

(19)



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European Patent Office

Office européen des brevets



(11)

EP 1 312 932 A1

(12)

EUROPEAN PATENT APPLICATION

published in accordance with Art. 158(3) EPC

(43) Date of publication:

21.05.2003 Bulletin 2003/21

(51) Int Cl.7: G01R 31/34

(21) Application number: 01947850.2

(86) International application number:
PCT/JP01/05844

(22) Date of filing: 05.07.2001

(87) International publication number:
WO 02/006843 (24.01.2002 Gazette 2002/04)

(84) Designated Contracting States:

AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE TR

(30) Priority: 13.07.2000 JP 2000212896

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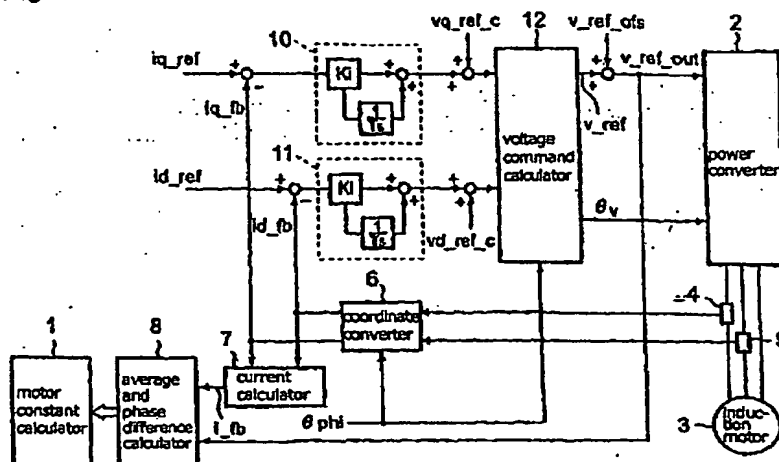
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(54) METHOD FOR MEASURING MOTOR CONSTANT OF INDUCTION MOTOR

(57) A method of measuring a motor constant is provided in a vector control apparatus for an induction motor. A voltage output phase θ_v is set at an previously set arbitrary phase. Prior to applying a current, a current command is fed to operate the vector control apparatus with a proportional-plus-integral controller being set operative. After conduction for a predetermined time, the

gain of the proportional-plus-integral controller is set to zero to maintain an integrated value constant and accordingly fix a voltage command value. In this state, a current command value and a detected current value are measured. k is measured at two levels of current, and a primary resistance value (or a line-to-line resistance value) is derived from the slope.

Fig. 1



Description

TECHNICAL FIELD

[0001] The present invention relates to a method of measuring a motor constant for an induction motor.

BACKGROUND ART

[0002] As a prior art, there is a software for controlling an inverter, which includes a method of determining a motor constant by conducting a winding resistance measurement, a lock test and a no-load test, as shown in JEC-37 (Prior Art Example 1). Also, JP-A-7-55899 discloses a method of tuning a constant of an induction motor while the induction motor remains inoperative (Prior Art Example 2). In this method, a single-phase AC current is supplied to an induction motor, and a detected d-axis current value or a detected q-axis current value is expanded in Fourier series to determine a constant of the induction motor. Here, d-q axis coordinates are rotating coordinates which rotate at the same velocity as a rotating magnetic field of the motor.

[0003] The method shown in Prior Art Example 1 is not suitable for automatic measurements by means of driving an inverter because it involves operations for fixing a rotor of an induction motor and releasing the fixation between a lock test and a no-load current test.

[0004] Also, in the no-load current test, the induction motor must be operated alone, so that if a load has been coupled thereto, an operation is required for once disconnecting the load to leave the motor alone, thus incurring a problem of a low efficiency.

[0005] Prior Art Example 2 needs complicated software because a single-phase AC current is applied and Fourier series expansion is utilized for the determination of a motor constant, thus requiring a long software processing time, and a large memory capacity for the software.

DISCLOSURE OF THE INVENTION

[0006] It is therefore an object of the present invention to provide a method of measuring a motor constant for an induction motor which is capable of accurately tuning the constant of the induction motor even when a load is coupled to the induction motor, and involves only simple processing therefor.

[0007] The present invention is directed to a motor vector control apparatus for a motor which separates a motor primary current into a flux component (d-axis component) and a torque component (q-axis component), and has a d-axis current proportional-plus-integral controller which receives a current command for a d-axis component and a detected current value of the d-axis component for controlling a deviation between both to reduce to zero; a first adder for adding an output of this proportional-plus-integration controller and an arbitrary d-axis auxiliary voltage command value to derive a d-axis voltage command value; a q-axis current proportional-plus-integral controller which receives a current command for a q-axis component and a detected current value of the q-axis component for controlling a deviation between both to reduce to zero; a second adder for adding an output of this proportional-plus-integral controller and an arbitrary q-axis auxiliary voltage command value to derive a q-axis voltage command value; and a power converter for calculating a magnitude v_{ref} and a voltage phase θ_v of a voltage command from the d-axis voltage command value and the q-axis voltage command value, and converting a DC current to a three-phase AC current based on the magnitude of the voltage command and the phase of the voltage command to provide the three-phase AC current. The vector control apparatus is configured to convert the motor to an equivalent circuit of a three-phase Y (star) connection to handle and control the motor.

[0008] The vector control apparatus is operated by applying the same with a d-axis current command value i_{d_ref1} and a q-axis current command value i_{q_ref1} previously set at arbitrary fixed values as first command values, and with the d-axis auxiliary voltage command vd_ref_c and the q-axis auxiliary voltage command value vq_ref_c both set at zero. After the lapse of a previously set first time, a proportional gain of the d-axis proportional-plus-integral controller and a proportional gain of the q-axis proportional-plus-integral controller are set to zero. After the lapse of a previously set second time from this time, the voltage command:

$$v_{ref} = \sqrt{(vd_ref^2 + vq_ref^2)}$$

is created from the d-axis voltage command vd_ref and the q-axis voltage command vq_ref , and the detected current value:

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$$i_{fd} = \sqrt{(i_{d_fb}^2 + i_{q_fb}^2)}$$

is created from the d-axis detected current value i_{d_fb} and the q-axis detected current value i_{q_fb} . An average of v_{ref} and an average of i_{fb} recorded within an arbitrary time during the second time are set as first data v_{ref1} , i_{fb1} , respectively.

[0009] Next, the vector control apparatus is operated, after the gains of both proportional-plus-integral controllers are returned to original values, by applying a d-axis current command value i_{d_ref2} and a q-axis current command value i_{q_ref2} previously set at arbitrary fixed values as second command values, and applying the d-axis auxiliary voltage command value $v_{d_ref_c}$ and the q-axis auxiliary voltage command value $v_{q_ref_c}$ set at zero. After the lapse of the previously set first time, the proportional gain of the d-axis current proportional-plus-integral controller and the proportional gain of the q-axis current proportional-plus-integral controller are set to zero. After the lapse of a previously set second time from this time, a primary resistance of the motor is calculated in accordance with:

$$R1 = \{v_{ref2} - v_{ref1}\} / \sqrt{3} / (i_{fb2} - i_{fb1})$$

using an average of v_{ref} and an average of i_{fb} recorded within an arbitrary time during the second time as second data v_{ref2} , i_{fb2} , respectively, and a line-to-line resistance of the motor is calculated in accordance with $R_{LL} = 2 \cdot R1$.

[0010] Alternatively, the gains and outputs of the proportional-plus-integral controllers, the d-axis auxiliary voltage command and the q-axis auxiliary voltage command are set to zero, a previously set arbitrary fixed value is set to a voltage phase θ_v , and a magnitude v_{ref} of the voltage command is given by $v_{ref} = v_{amp} \cdot \sin(2 \cdot \pi \cdot f_h \cdot t)$, where f_h is a proper frequency 1/10 or more as high as a rated operation frequency of the motor, and v_{amp} is a voltage amplitude. V_{amp} is incrementally or decrementally adjusted while monitoring the current value i_{fb} such that:

$$i_{fb} = \sqrt{(i_{d_fb}^2 + i_{q_fb}^2)}$$

calculated from a d-axis detected current value i_{d_fb} and a q-axis detected current value i_{q_fb} reaches a first set current value. After i_{fb} reaches the first set current value, an average of an absolute value of the magnitude v_{ref} of the voltage command is set to v_{ref_ave1} ; an average of an absolute value of the magnitude of the detected current value i_{fb} to i_{fb_ave1} , and the phase of i_{fb} with respect to v_{ref} to θ_{dif1} after the lapse of an arbitrarily set time.

[0011] Next, v_{amp} is adjusted to reach a previously set second set current value, and after the lapse of the set time, the average of the absolute value of the magnitude v_{ref} of the current command is set to v_{ref_ave2} ; the average of the absolute value of the magnitude of the detected current value i_{fb} to i_{fb_ave2} ; and the phase of i_{fb} with respect to v_{ref} to θ_{dif2} for calculating:

$$Zx = \{(v_{ref_ave2} - v_{ref_ave1}) / \sqrt{3} / (i_{fb_ave2} - i_{fb_ave1}), \theta_{dif_L} = (\theta_{dif1} + \theta_{dif2}) / 2$$

$$Zx_r = Zx \cdot \cos \theta_{dif_L}, Zx_l = Zx \cdot \sin \theta_{dif_L}$$

From these, a secondary resistance of the motor is calculated in accordance with $R2 = Zx_r - R1$, and a leakage inductance in accordance with $L = Zx_l / (2 \cdot \pi \cdot f_h)$.

[0012] Alternatively, the gains and outputs of the proportional-plus-integral controllers, the d-axis auxiliary voltage command and the q-axis auxiliary voltage command are set to zero, and a previously set arbitrary fixed value is set to a voltage phase θ_v . A magnitude v_{ref} of the voltage command is given by $v_{ref} = v_{amp} \cdot \sin(2 \cdot \pi \cdot f_l \cdot t)$, where f_l is a proper frequency 1/5 or less as high as the rated operation frequency of the motor, and v_{amp} is a voltage amplitude. V_{amp} is incrementally or decrementally adjusted while monitoring the current value i_{fb} such that:

$$i_{fb} = \sqrt{(i_{d_fb}^2 + i_{q_fb}^2)}$$

calculated from a d-axis detected current value i_{d_fb} and a q-axis detected current value i_{q_fb} reaches a previously arbitrarily set first set current value. After i_{fb} reaches the first set current value, an average of an absolute value of the magnitude v_{ref} of the voltage command is set to v_{ref_ave3} ; an average of an absolute value of the magnitude of the detected current value i_{fb} to i_{fb_ave3} ; and the phase of i_{fb} with respect to v_{ref} to θ_{dif3} after the lapse of a first arbitrary set time.

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[0013] Next, v_{ref} is adjusted to reach a previously set second set current value, and after the lapse of a second arbitrary set time, the average of the absolute value of the magnitude v_{ref} of the current command is set to v_{ref_ave4} ; the average of the absolute value of the magnitude of the detected current value i_{fb} to i_{fb_ave4} ; and the phase of i_{fb} with respect to v_{ref} to θ_{dif4} for calculating:

$$Zx2 = (v_{ref_ave4} - v_{ref_ave3}) / \sqrt{3} / (i_{fb_ave4} - i_{fb_ave3}), \theta_{dif_m} = (\theta_{dif3} + \theta_{dif4}) / 2$$

$$Zx_r2 = Zx \cdot \cos \theta_{dif_m}$$

From these, a mutual inductance of the motor is calculated in accordance with:

$$M = \frac{R2}{2 \cdot \pi \cdot f1} \cdot \sqrt{\frac{Zx_r2 - R1}{R1 + R2 - Zx_r2}}$$

[0014] The present invention is also directed to an induction motor in a motor control apparatus which is configured to supply a three-phase AC current to the induction motor through an inverter to operate the motor at a variable velocity, and has a current detector for detecting the current flowing at two arbitrary phases or three phases of an inverter output; a proportional-plus-Integral controller which receives a current command value for a primary current fed to the motor, and a primary current value i_{fb} of a primary current detector derived from a current value detected by the current detector to control an output voltage command value v_{ref} such that a deviation between both reduces to zero, and a power converter for providing a three-phase AC current based on the voltage command value v_{ref} and a voltage output phase θ_v . The motor control apparatus is configured to convert the motor to an equivalent circuit of a three-phase Y (star) connection to handle the equivalent circuit.

[0015] The voltage output phase θ_v is chosen at a previously set arbitrary phase. Prior to applying a current, a current command is fed to operate the vector control apparatus with a proportional-plus-integral controller being set operative. After conduction for a predetermined time, a current command value and a detected current value are measured, k is measured at two levels of current, and a primary resistance value (or a line-to-line resistance value) is derived from the slope of the current at that time with the gain of the current controller being set to zero to maintain an integrated value constant and accordingly fix a voltage command value.

[0016] Also, the voltage phase θ_v is chosen at a previously set arbitrary value, and the magnitude v_{ref} of the voltage command is fed in sinusoidal wave. An average of the voltage command value and an average of the detected current value, as well as a difference in phase between the voltage command value and detected current value are calculated respectively at two frequencies. An impedance is determined from the voltage command value and detected current value, and the impedance is decomposed into a real component and an imaginary component by the phase difference. (Primary resistance value + Secondary resistance value) is calculated from the real component, while the impedance due to a leakage inductance is calculated from the imaginary component. From these, the second resistance value and leakage inductance are found.

[0017] The present invention is directed to a motor control apparatus which separates a primary current of a motor separated into a flux component (d-axis component) and a torque component (q-axis component) for a no-load current value, and has a d-axis current proportional-plus-Integral controller which receives a current command of the d-axis component and a detected current value of the d-axis component for controlling a deviation between both to reduce to zero, wherein the output of the proportional-plus-Integral controller is set to a d-axis voltage command value;

a q-axis current proportional-plus-integral controller which receives a current command of the q-axis component and a detected current value of the q-axis component for controlling a deviation between both to reduce to zero, wherein the output of the proportional-plus-integral controller is set to a q-axis voltage command value; and a power converter for calculating a magnitude v_{ref} and a voltage phase θ_v of a voltage command from the d-axis voltage command value which is an output of the d-axis current proportional-plus-Integral controller and the q-axis voltage command value which is an output of the q-axis current proportional-plus-integral controller, and converting a DC current to a three-phase AC current based on the magnitude of the voltage command and the phase of the voltage command to provide the three-phase AC current, wherein the motor control apparatus is configured to control the d-axis current command and the q-axis current command to operate the motor in conformity with an arbitrary velocity command.

[0018] In a normal operating condition, an output frequency f_{phi} , the d-axis voltage command vd_{ref} , the q-axis voltage command vq_{ref} , a d-axis detected current value id_{fb} , and a q-axis detected current value iq_{fb} are measured.

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Both or one of a mutual inductance M and a no-load current I₀ of the motor is determined using a previously set base voltage v_{base} and base frequency f_{base} of the motor, a primary resistance value R₁, and a leakage inductance L.

[0019] The present invention is also directed to a motor control apparatus configured to supply a three-phase AC current to the induction motor through an inverter to operate the motor at a variable velocity, which has a power converter for providing the three-phase AC current based on an output voltage command value v_{ref} and a voltage output phase θ_v, and a current detector for detecting a primary current flowing into the induction motor, wherein a detected primary current value i₁ derived from a current value detected by the current detector is fed to the motor control apparatus.

[0020] An equivalent circuit per phase of the induction motor is created in the form of T-1 type equivalent circuit.

[0021] The voltage phase θ_v is set to a previously set arbitrary fixed value, and a predetermined fixed value to the voltage command value v_{ref}. The detected primary current value i₁ flowing into the induction motor at this time is read, and a current i_m flowing through a mutual inductance M is estimated in accordance with:

$$i_m = (1 + \frac{R_1}{R_2}) \cdot i_1 - \frac{v_{ref}}{R_2}$$

using the primary current value i₁ and a primary resistance value R₁ and a secondary resistance value R₂ given by a separate means. A time constant τ_{im} is determined from the waveform of the estimate i_m of the rising current, and the mutual inductance M is calculated in accordance with:

$$M = \frac{R_1 \cdot R_2}{R_1 + R_2} \cdot \tau_{im}$$

[0022] The no-load current I₀ is calculated as required, using the mutual inductance M or the time constant τ_{im}, the primary resistance value R₁, a leakage inductance L and the secondary resistance value R₂ given by a separate means, and a rated voltage V_{rate} and a rated frequency f_{rate} given as the rating of the motor, and the mutual inductance M.

[0023] Alternatively, a current i_m flowing through the mutual inductance M is estimated using the primary current value i₁, and a primary resistance value R₁ and a secondary resistance value R₂ given by a separate means in accordance with:

$$i_m = i_1 - \frac{R_1}{R_2} (i_1 - i_0)$$

without using a voltage value, where i₀ represents a constant value to which the primary current value i₁ converges when the voltage command v_{ref} is applied.

[0024] According to the present invention it is possible to accurately tune the primary resistance and secondary resistance, a leakage inductance and a mutual inductance or a no load current, which are required for accurately controlling an induction motor, even when a load is coupled to the induction motor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025]

Fig. 1 is a block diagram of an induction motor control apparatus according to one embodiment of the present invention;

Fig. 2 is a configuration diagram of average/phase difference processor 8;

Fig. 3 is a T-1 type equivalent circuit diagram of an induction motor;

Fig. 4 is an equivalent circuit diagram during primary resistance tuning;

Fig. 5 is a time chart of a voltage command value and a detected current value during the primary resistance tuning;

Fig. 6 is a graph of the voltage command value and detected current value during the primary resistance tuning;

Fig. 7 is an equivalent circuit diagram during secondary resistance and leakage inductance tuning;

Fig. 8 is a vector diagram of an impedance in the equivalent circuit during the secondary resistance and leakage inductance tuning;

Fig. 9 is a time chart of a voltage command value and a detected current value during the secondary resistance and leakage inductance tuning;

Fig. 10 is a block diagram when a tenth embodiment is applied;

Fig. 11 is a block diagram when eleventh to thirteenth and seventeenth embodiments are applied;

Fig. 12 is a T-1 type equivalent circuit diagram of an induction motor;

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Fig. 13 is an equivalent circuit diagram when a DC current is fed to the Induction motor;
 Fig. 14 is a time chart of a voltage command value and a detected current value during primary resistance tuning;
 Fig. 15 is a graph of the voltage command value and detected current value during the primary resistance tuning;
 Fig. 16 is a block diagram when a fourteenth and a fifteenth embodiment are applied;
 Fig. 17 is a configuration diagram of average/phase difference processor 8;
 Fig. 18 is an equivalent circuit during secondary resistance and leakage Inductance tuning;
 Fig. 19 is a time chart of a voltage command value and a detected current value during the secondary resistance and leakage Inductance tuning;
 Fig. 20 is a vector diagram of an Impedance in the equivalent circuit during the secondary resistance and leakage Inductance tuning;
 Fig. 21 is a diagram showing a change due to the frequency of a real component of the impedance in the equivalent circuit during the secondary resistance and leakage Inductance tuning;
 Fig. 22 is a diagram showing the relationship between a current and a voltage value when signals at 15 Hz and 30 Hz are applied;
 Fig. 23 is a block diagram when a sixteenth to a nineteenth embodiment are applied;
 Fig. 24 is a T-1 type equivalent circuit diagram of an Induction motor; and
 Fig. 25 is a diagram showing a time-varying waveform of a current when the Induction motor is applied with a DC voltage.

BEST MODE FOR CARRYING OUT THE INVENTION

[0026] Fig. 1 is a block diagram illustrating the configuration of one embodiment of an Induction motor control apparatus in the present invention. Proportional-plus-Integral controller 10 performs a control such that a deviation between q-axis current command i_{q_ref} and detected q-axis current value i_{q_fb} becomes zero, and q-axis auxiliary voltage command $v_{q_ref_c}$ is added to the output of proportional-plus-integral controller 10 to create q-axis voltage command v_{q_ref} . Similarly, proportional-plus-Integral controller 11 performs a control such that a deviation between d-axis current command i_{d_ref} and detected d-axis current value i_{d_fb} becomes zero, and d-axis auxiliary voltage command $v_{d_ref_c}$ is added to the output of proportion integration controller 11 to create d-axis voltage command v_{d_ref} . A proportional gain of a proportional Integrator is represented by K_I , and an integral gain by $(1/T)$. Voltage command processor 12 calculates magnitude v_{ref} and voltage phase θ_v of a voltage command from v_{q_ref} and v_{d_ref} , and also adds phase θ_{phi} of magnetic flux to θ_v to calculate a voltage phase on three-phase AC coordinates. Also, voltage command offset value v_{ref_ofs} is added to the magnitude v_{ref} of the voltage command. Here, i_{q_ref} , i_{d_ref} and θ_{phi} are given by separately provided calculation circuits during a normal operating condition of an Induction motor. Power converter 2 serves to supply Induction motor 3 with a three-phase AC voltage based on the above-mentioned $v_{ref}+v_{ref_ofs}$ and θ_{ref} . Currents flowing into Induction motor 3 are detected by current detectors 4 and 5, and fed to coordinate converter 6 where they are converted to i_{q_fb} and i_{d_fb} on d-q coordinates. i_{q_fb} and i_{d_fb} are converted to magnitude i_{fb} of their composite vector by current processor 7. Average and phase difference calculator 8 is a calculator for calculating averages of the voltage command and detected current value as well as a phase difference between the voltage command and detected current value, which are required for calculating a motor constant of Induction motor 3, from $v_{ref}+v_{ref_ofs}$ and i_{fb} . Motor constant processor 1 is a calculator for calculating the motor constant of Induction motor 3 based on signals calculated by average and phase difference calculator 8.

[0027] Fig. 2 illustrates the specific configuration of average and phase difference calculator 8, that calculates, from v_{ref_out} and i_{fb} , a phase difference between them, averages of absolute values of respective frequency components, and DC components. Here, the average is derived through a low pass filter (LPF), but may be calculated in accordance with a method based on moving average or the like.

[0028] Fig. 3 illustrates a T-1 type equivalent circuit of an Induction motor which is used for determining a motor constant of the Induction motor in this embodiment. Fig. 3 is an equivalent circuit for each phase, and is applied with a voltage expressed by:

$$v_{ref}/\sqrt{3}$$

i_1 is a primary current of the motor; R_1 is a primary resistance of the motor; R_2 is a secondary resistance of the motor; L_1 is a leakage Inductance of the motor; and M is a mutual Inductance of the motor.

A first embodiment will be described.

[0029] When a DC current is applied to Induction motor 3, impedance ωM at mutual Inductance M is zero, so that

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the equivalent circuit in Fig. 3 is changed as illustrated in Fig. 4. Therefore, primary resistance R1 is calculated in accordance with:

$$R1 = (v_ref/\sqrt{3})/I1$$

[0030] When setting as a line-to-line resistance, $RL=2 \cdot R1$ is handled as the line-to-line resistance. As tuning is started for the primary resistance, i_{q_ref} and i_{d_ref} are applied as primary current command values arbitrarily set as a current command. As the current command is given, a voltage command is generated in accordance with the gain of proportional-plus-integral controllers 10, 11, and a three-phase AC voltage is delivered from power converter 2 and applied to motor 3 through which current I1 flows. Current I1 is detected by current detectors 4, 5, subjected to coordinate conversion and current processing, and resulting I_{fb} is applied to motor constant processor 1. A time required for the current to rise is determined by the gain of proportional-plus-integral controllers 10, 11, so that this time is set as a previously set arbitrary time, and the proportional gain of the q-axis and d-axis proportional-plus-integral controllers is set to zero after the lapse of the set time. Since this causes zero to be fed to the integrator, the output of the proportional controller is fixed to an output value immediately before the proportional gain is set to zero, thereby stably maintaining the voltage command at a fixed value. Waiting a constant time in this state, averages are measured for voltage command v_ref and detected current value I_{fb} during the time, and are set to v_ref1 and I_{fb1} , respectively. Next, the proportional gain of proportional-plus-integral controllers 10, 11 is returned to an original value, and current command values i_{q_ref} and i_{d_ref} are used as second set current values, and are manipulated in a similar manner. Averages of the voltage command values and current command values at this time are set to v_ref2 , I_{fb2} , respectively. A change over time in voltage command v_ref and detected current value I_{fb} in this event are shown in Fig. 5. The relationship between v_ref1 , I_{fb1} , v_ref2 , I_{fb2} is established as shown in Fig. 6, wherein primary resistance value R1 is determined from the slope of this linear line. Considering that v_ref is a line-to-line value, R1 is given by:

$$R1 = \{(v_ref2 - v_ref1) / \sqrt{3}\} / (I_{fb2} - I_{fb1})$$

[0031] A second embodiment will be described.

[0032] The present embodiment is a modification of the first embodiment described above, wherein when proportional gain K_i of proportional-plus-integral controllers 10, 11 is set to zero, the q-axis and d-axis voltage commands at that time are substituted into auxiliary voltage command values $v_{q_ref_c}$ and $v_{d_ref_c}$, respectively, and simultaneously, proportional gain K_i and integral gain $(1/T)$ of proportional-plus-integral controllers 10, 11, and the outputs of proportional-plus-integral controllers 10, 11 are set to zero, such that a resulting voltage command is applied. The remaining processing is the same as the first embodiment.

[0033] A third embodiment will be described.

[0034] While the current level is measured at two points in the first and second embodiments described above, the measurements are made at three points or more for improving the measurement accuracy in this embodiment. Describing for measurements at three points, when measurements are made at points 1, 2, 3, R1 is calculated in intervals between points 1 and 2, between points 2 and 3, and between points 1 and 3, respectively, or in arbitrary two of these intervals, as is the case in the first and second embodiments, and an average of calculated values is employed as R1 which should be determined. For measurements at four points or more, R1 may be similarly calculated in arbitrary intervals, such that an average of calculated values is used.

[0035] A fourth embodiment will be described.

[0036] The voltage command is given as $v_ref = v_{amp} \sin(2\pi \cdot fh \cdot t)$, and θ_{ref} as an arbitrary fixed value. v_{amp} is initially set to zero, and fh is set to a value equal to or higher than the rated operation frequency of the motor. When the frequency is high, an equivalent circuit becomes as illustrated in Fig. 7 on the assumption that a current hardly flows into M because $\omega M \gg R2$ stands in the equivalent circuit illustrated in Fig. 3. When the phase difference between the voltage and current at this time is represented by θ_{dif} , the relationship between $(R1 + R2)$ and $\omega 1$ is established as shown in Fig. 8, represented by $(R1 + R2) = |Zx| \cdot \cos \theta_{dif}$, and $\omega 1 = |Zx| \cdot \sin \theta_{dif}$, where $|Zx|$ indicates the impedance of the circuit. Thus, R2 and L can be derived using previously determined R1.

[0037] For determining $|Zx|$, v_ref shown above is applied, and v_{amp} is gradually increased until average i_{fb_ave} of the absolute value of the detected current value reaches a previously set first set current value. When i_{fb_ave} matches the set value, average v_ref_ave of the absolute value of a frequency component of v_ref , average i_{fb_ave} of the absolute value of the detected current value, and phase difference θ_{dif} are stored in a memory as v_ref_ave1 , i_{fb_ave1} , θ_{dif1} , respectively, after waiting for a certain time until the output of the filter becomes stable. Next, v_{amp} is adjusted such that average i_{fb_ave} reaches a previously set second set current value, and the value is similarly read when i_{fb_ave} matches the second set current value. Then, average v_ref_ave , average i_{fb_ave} and phase

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difference θ_{dif} are stored as v_{ref_ave2} , i_{fb_ave2} , θ_{dif2} , respectively. Fig. 9 shows a change over time in the voltage command and detected current value in this case. Impedance $|Z_x|$ of the circuit is calculated in accordance with:

$$|Z_x| = \{(v_{ref_ave2} - v_{ref_ave1}) / \sqrt{3}\} / (i_{fb_ave2} - i_{fb_ave1})$$

as the slope of the voltage and current, as in the case of R_1 .

[0038] The phase difference is calculated in accordance with $\theta_{dif_L} = (\theta_{dif1} + \theta_{dif2}) / 2$.

[0039] From this equation and the aforementioned equation, secondary resistance R_2 and leakage inductance L are calculated in accordance with:

$$R_2 = \{(v_{ref_ave2} - v_{ref_ave1}) / \sqrt{3}\} / (i_{fb_ave2} - i_{fb_ave1}) - \cos \theta_{dif_L} R_1,$$

$$L = \{[(v_{ref_ave2} - v_{ref_ave1}) / \sqrt{3}] / (i_{fb_ave2} - i_{fb_ave1}) - \sin \theta_{dif_L}\} / (2 \cdot \pi \cdot f_h)$$

[0040] While the explanation has been made with the initial value for v_{amp} being zero, the value of a flowing current can be predicted with reference to a V/f pattern, so that a reduction in time can be made by previously setting some value and increasing or decreasing from this value.

[0041] A fifth embodiment will be described.

[0042] The present embodiment is a modification of the fourth embodiment, wherein v_{ref_ofs} is added to voltage command v_{ref} as an offset value, and the resulting value is used as a voltage command. As illustrated in Fig. 2, data v_{ref_ave} , i_{fb_ave} , θ_{dif} for use in calculating $R_1 + R_2$ and L can be handled in a similar manner to the fourth embodiment by using data from which a DC component is removed by passing an input signal through a high pass filter.

[0043] An embodiment of the invention of claim 6 will be described.

[0044] The present embodiment is a modification of the fourth embodiment, wherein v_{ref_ofs} is added to voltage command v_{ref} as an offset value, and the resulting value is used as a voltage command. Since the voltage equivalent to the offset value is provided as a DC component, an equivalent circuit therefor is that illustrated in Fig. 4, so that primary resistance R_1 is determined by calculating the ratio of a DC component of this voltage command value to a DC component of the detected current value. To extract a DC component of a signal, the signal may be averaged. In the embodiment, a low pass filter [LPF3] is used for detection as illustrated in Fig. 2. The value of v_{ref_ofs} is determined herein by adjusting v_{ref_ofs} , while comparing the detected current value with the set current value in a manner similar to the fourth embodiment, before an AC signal is applied.

[0045] The sixth embodiment is the same as the embodiment in claim 4 except that R_1 thus determined is used for calculating R_2 . In this way, since R_1 , R_2 , L can be determined in a single step, the execution time can be reduced.

[0046] An embodiment of the invention of claim 7 will be described.

[0047] In the fourth embodiment, frequency f_1 is set at a very low frequency with respect to the rated operation frequency of the motor. In this event, since a current flowing into M cannot be ignored, the equivalent circuit illustrated in Fig. 3 is based on the following discussion.

[0048] The equivalent circuit is expressed by the equation:

$$\left(R_1 + j\omega L + \frac{j\omega M R_2}{R_2 + j\omega M} \right) I_1 = v_{ref} / \sqrt{3}, \omega = 2 \cdot \pi \cdot f_h$$

[0049] This equation is solved to derive:

$$\frac{R_1 R_2^2 + \omega^2 M^2 R_1 + \omega^2 M^2 R_2}{R_2^2 + \omega^2 M^2} + j \frac{\omega L R_2^2 + \omega^3 L M^2 + \omega M R_2}{R_2^2 + \omega^2 M^2} = \frac{v_{ref} / \sqrt{3}}{I_1} = Z_r + jZ_i$$

where:

$$Z_r = \frac{v_{ref} / \sqrt{3}}{I_1} \cdot \cos \theta_m, Z_i = \frac{v_{ref} / \sqrt{3}}{I_1} \cdot \sin \theta_m, \theta_m = \tan^{-1} \left(\frac{\omega L R_2^2 + \omega^3 L M^2 + \omega M R_2}{R_1 R_2^2 + \omega^2 M^2 R_1 + \omega^2 M^2 R_2} \right)$$

M is calculated by comparing real parts:

$$M = \frac{R_2}{\omega} \cdot \sqrt{\frac{Z_r - R_1}{R_1 + R_2 - Z_r}}$$

Thus, M is derived.

[0050] Here, when M is calculated in a similar manner to the fourth embodiment except that f_h is set at a low frequency, and the impedance is represented by $|Z_{x2}|$ and the phase difference by θ_{dif_m} ,

$$Z_{x_r2} = |Z_{x2}| \cdot \cos \theta_{dif_m}$$

[0051] From this and previously determined R_1 , R_2 , mutual inductance M is calculated in accordance with:

$$M = \frac{R_2}{2 \cdot \pi \cdot f_1} \cdot \sqrt{\frac{Z_{x_r2} - R_1}{R_1 + R_2 - Z_{x_r2}}}$$

[0052] Eighth and ninth embodiments will be described.

[0053] In the present embodiment, similar to those shown in the fifth and sixth embodiments, v_{ref_ofs} is added to voltage command v_{ref} as an offset. Details on the processing are the same as those shown in the fifth and sixth embodiments. Since the frequency is low in the seventh embodiment, the motor can be prevented from unnecessarily moving by applying a DC offset, as shown in this method.

[0054] A tenth embodiment will be described.

[0055] Fig. 10 illustrates a block diagram in which the invention in claim 10 is implemented. From a configuration for conducting a normal vector control, q-axis voltage command value v_{q_ref} , d-axis voltage command value v_{d_ref} , q-axis detected current value i_{q_fb} , d-axis detected current value i_{d_fb} , and output frequency value f_{phi} are extracted and fed to motor constant calculator 1 to calculate mutual inductance M and no-load current value I_0 . Velocity controller 14 calculates q-axis current command value i_{q_ref} , d-axis current command value i_{d_ref} and output frequency value f_{phi} based on a velocity command in accordance with a generally used vector control scheme. Velocity controller 14 is simplified for description since it does not relate to the features of the present invention. Coordinate converter 6 is a coordinate converter for converting a detected phase current value to a value in a dq-coordinate system. q-axis PI current controller 10 and d-axis PI current controller 11 are controllers for controlling the current command value to match the detected current value.

Voltage command calculator 12 calculates magnitude v_{ref} and voltage phase θ_v of a three-phase AC voltage from the q-axis voltage command, d-axis voltage command value, and magnetic flux phase θ_{phi} . Magnetic flux phase θ_{phi} is calculated by integrating output frequency f_{phi} . Power converter 2 supplies three-phase AC power to induction motor 3 based on v_{ref} and θ_v .

[0056] Here, after an operation command is fed, output frequency f_{phi} , d-axis voltage command v_{d_ref} , q-axis voltage command v_{q_ref} , d-axis detected current value i_{d_fb} , and q-axis detected current value i_{q_fb} are read after the lapse of one second from the time an acceleration of induction motor 3 is completed, and the following equations:

$$V_{qq} = \frac{v_{q_ref}}{\sqrt{3}} - R_1 \cdot i_{q_fb} - 2\pi \cdot f_{phi} \cdot L \cdot i_{d_fb}$$

$$V_{dd} = \frac{v_{d_ref}}{\sqrt{3}} - R_1 \cdot i_{d_fb} - 2\pi \cdot f_{phi} \cdot L \cdot i_{q_fb}$$

$$Q = V_{q\dot{q}} \cdot i_{d_fb} - V_{q\dot{q}} \cdot i_{q_Fb}$$

$$E = \sqrt{V_{q\dot{q}}^2 + V_{dd}^2}$$

$$M = \frac{E^2}{2\pi \cdot f_{phi} \cdot Q}$$

$$I_0 = \frac{v_base / \sqrt{3}}{2\pi \cdot f_base (M + L)}$$

are calculated using previously set base voltage v_base and base frequency f_base of the motor, and separately calculated primary resistance value $R1$ and leakage inductance L to determine mutual inductance M and no-load current I_0 of the motor.

[0057] While it is assumed the measurements are made upon completion of the acceleration, the measurement may be made at any arbitrary time during operation.

[0058] The method according to the present invention extracts signals from the respective components for calculations in a normal operating condition, and can therefore be applied irrespective of a difference in configuration of the velocity controller due to the presence or absence of PG and the like.

[0059] Fig. 11 is a block diagram illustrating the configuration of a motor control apparatus which implements the method of measuring a motor constant for an induction motor in the eleventh to thirteenth embodiments. Motor constant calculator 1 delivers current command i_ref . The values of currents flowing into induction motor 3 are captured as current i_u detected by current detector 4 for U-phase and current i_v detected by current detector 5 for v-phase. Three-phase/two-phase converter 6 performs calculations expressed by Equations (1) and (2) to convert i_u and i_v to two-phase AC currents i_α and i_β .

$$i_w = -(i_u + i_v) \quad (1)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_u \\ i_v \\ i_w \end{bmatrix} \quad (2)$$

[0060] The phases at which currents are detected are not limited to a combination of U-phase and v-phase, but the current may be detected at two arbitrary phases or at all the three phases.

[0061] Current calculator 7 calculates a square root of the sum of squared two-phase AC currents i_α , i_β to find detected current value i_fb . i_fb is fed to average and phase difference calculator 8 to calculate average i_fb_ave . While the average is herein calculated by taking the absolute value of i_fb and passing the result through a low pass filter, another method such as moving average may be used to calculate the average. Current Proportional-plus-integration controller 13 performs a control such that current command i_ref matches average detected current value i_fb_ave . The output of current Proportional-plus-integration controller 13 is voltage command v_ref . Power converter 2 converts voltage command value v_ref into a line-to-line voltage, calculates the output phase of a three-phase AC current using voltage phase θ_v applied from motor constant calculator 1, and supplies induction motor 3 with three-phase AC power.

[0062] An eleventh embodiment will be described.

[0063] Fig. 12 illustrates a T-1 type equivalent circuit for one phase of an induction motor. $R1$ represents a primary resistance; L a leakage inductance; M a mutual inductance; $R2$ a secondary resistance; and s a slippage. When a DC current is fed, an impedance component of mutual inductance M is zero, so that the equivalent circuit is changed as illustrated in Fig. 13.

[0064] The following description will be made on the assumption that the phase is at 0° when a current at U-phase reaches a peak.

[0065] In this embodiment, voltage phase θ_v is at 0° .

[0066] First, when a value equal to 20 % of the rated current of the induction motor is applied as current command value i_{ref} , voltage command v_{ref} is changed as shown in Fig. 14 by the action of current Proportional-plus-Integration controller 13. At the time detected current value i_{fb_ave} matches i_{ref1} , v_{ref} becomes constant. Here, the width of section A for controlling the current over time is determined by waiting for two seconds. Since the time until the stability is ensured is related to control characteristics, a wait for two seconds is generally sufficient. However, if the gain of current Proportional-plus-Integration controller 13 cannot be increased due to the characteristics of a load machine or the like, this time should be extended. After the lapse of two seconds, gain K_i of current Proportional-plus-Integration controller 13 is set to zero, and the value saved in the Integrator is delivered as v_{ref} , thereby fixing current command value v_{ref} . After waiting a certain time (here, one second), v_{ref_ave} which is an average of v_{ref} , and i_{fb_ave} which is an average of i_{fb} are read, and set to v_{ref1} , i_{fb1} , respectively, v_{ref_ave} is calculated by feeding the value of v_{ref} to average and phase difference calculator 8. Next, 40 % of the rated current of the induction motor is applied as current command i_{ref} , and a similar control is conducted. Then, voltage command value v_{ref_ave} and detected current value i_{fb_ave} are read, and set to v_{ref2} , i_{fb2} , respectively. The data at two points are plotted as shown in Fig. 15. Since this slope represents primary resistance value R_1 , R_1 is calculated in accordance with:

$$R_1 = \{(v_{ref2} - v_{ref1}) / \sqrt{3}\} / (i_{fb2} - i_{fb1})$$

[0067] Then, $2xR_1$ is set to line-to-line resistance value R_{L-L} . While the current value is set herein to 20 % and 40 % of the rated current of the induction motor, different values may be used, or the foregoing operation may be performed at three points or more of the current value.

[0068] In the twelfth embodiment, measurements at three points or more are made. When the measurements are made, for example, at three points of current values 20 %, 40 %, 60 %, the slopes are calculated respectively between 20 % and 40 %, between 40 % and 60 % and between 20 % and 60 %. The slopes may be averaged for use.

[0069] A thirteenth embodiment will be described. As shown in Fig. 15, the previously measured data is approximated by a linear function and extended for recording the value of v_{ref} when the current value is zero, as voltage offset value v_{ref0} . This corresponds to a voltage drop caused by devices used for power converter 2 and the like. When the measurements are made at three points or more of the current value, the voltage offset value may be found by linear approximation of two arbitrary points or a regression curve based on a mean square error method.

[0070] A fourteenth embodiment will be described. Figs. 16 and 17 are block diagrams for implementing methods described in claims 14 and 15.

[0071] In Fig. 15, output voltage command v_{ref} and output voltage phase θ_v are applied from motor constant calculator 1 to power converter 2 to supply a three-phase AC current based thereon for operating induction motor 3. The value of the current flowing into induction motor 3 is captured as current i_u detected by current detector 4 for U-phase and current i_v detected by current detector 5 for v-phase. Coordinate converter 6 performs the calculations expressed by Equations (1) and (2) to convert i_u and i_v to two-phase AC currents i_α and i_β . The phases at which the currents are detected are not limited to a combination of U-phase and v-phase, but the current may be detected at two arbitrary phases or at all the three phases.

[0072] Current calculator 7 calculates a square root of the sum of squared two-phase AC currents i_α , i_β to find detected current value i_{fb} . Voltage command v_{ref} , detected current value i_{fb} , and phase θ_h at which an instantaneous value of the amplitude is given for v_{ref} applied by motor constant calculator 1, are fed to average and phase difference processor 8 which calculates v_{ref_ave} which is an average of v_{ref} , i_{fb_ave} which is an average of i_{fb} , and phase difference θ_{dif} which are fed to motor constant calculator 1 for calculating a motor constant. Differences of Fig. 15 from Fig. 11 are that voltage command v_{ref} is applied instead of the current command, and average and phase difference calculating circuit 8 is applied with phase θ_h of a frequency component which is given as voltage command v_{ref} . Fig. 17 is a block diagram illustrating the configuration of average and phase difference calculator 6. Average and phase difference processor 6 calculates v_{ref} , i_{fb_ave} which is an average of i_{ref} , and phase difference θ_{dif} based on the processing in the block diagram of Fig. 17.

[0073] The equivalent circuit of the induction motor illustrated in Fig. 12 can be approximated to a series circuit of R_1 , L , R_2 as illustrated in Fig. 18 because impedance ωM by mutual inductance M becomes larger as compared with R_2 at higher frequencies. Therefore, resistance component $R_1 + R_2$ and reactance component ωL are determined from the magnitudes of the voltage and current, and the phase difference between them.

[0074] In this embodiment, θ_v is set to 0° ; first frequency f_{h1} to 15 Hz; second frequency f_{h2} to 30 Hz; and the set current value described in the fourteenth embodiment to 80 % of the rated current of the induction motor. First, the induction motor is operated with the magnitude of the voltage amplitude V_{amp} set to zero, and the magnitude of the voltage command given by $v_{ref} = v_{amp} \sin(2\pi \cdot 15 \cdot t)$, where t is time. Voltage amplitude V_{amp} is adjusted while i_{fb} is monitored such that average detected current value i_{fb} reaches 80 % of the rated current of the induction motor. V_{amp} should be adjusted by an appropriate step which does not cause the current to suddenly change. In this embodiment,

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a step equal to 1/1000 of the rated voltage of the induction motor was added to or subtracted from V_{amp} . After average detected current value i_{fb} reaches 80 % of the rated current of the induction motor, an average of the absolute value of magnitude v_{ref} of the voltage command is set to v_{ref_ave1} ; an average of the absolute value of the magnitude of detected current value i_{fb} to i_{fb_ave1} ; and the phase of i_{fb} with respect to v_{ref} to θ_{dif1} after the lapse of an arbitrarily set time (here three seconds). Next, the frequency is set to 30 Hz at which a similar operation is performed to that at 15 Hz. In this event, an average of the absolute value of magnitude v_{ref} of the voltage command is set to v_{ref_ave2} ; an average of the absolute value of the magnitude of detected current value i_{fb} to i_{fb_ave2} ; and the phase of i_{fb} with respect to v_{ref} to θ_{dif2} . Here, respective saturated values are fed to low pass filters, the outputs of which are used for the averages. A time chart of the voltage command and detected current value at this time is shown in Fig. 19. When the relationship between the voltage, current and phase difference established herein is handled in complex numbers as shown in Fig. 20, the impedance, and its real component and imaginary component are given by the following equations:

$$Zx1 = (v_{ref_ave1}/\sqrt{3})/(i_{fb_ave1}), Zx2 = (v_{ref_ave2}/\sqrt{3})/(i_{fb_ave2})$$

$$Zxr1 = Zx1 \cdot \cos\theta_{dif_1}, Zxr2 = Zx2 \cdot \cos\theta_{dif_2},$$

$$Zxi1 = Zx1 \cdot \sin\theta_{dif_1}, Zxi2 = Zx2 \cdot \sin\theta_{dif_2},$$

[0075] In this event, real components $Zxr1$, $Zxr2$ represent resistance component $R1+R2$, while imaginary components $Zxi1$, $Zxi2$ represent reactance component ωL . First, consider the real components. $Zxr1$ at $fh1$ (15 Hz) and $Zxr2$ at $fh2$ (30 Hz) are graphically represented as shown in Fig. 21, and change together with the frequency. This is presumably due to the influence of a skin effect and the like. $R2$ is calculated in accordance with $R2=Zxr-R1$, whereas $R1$ is measured by feeding a DC current, so that a value when frequency fh is at 10 Hz ($fh=fh1 \cdot fh2/(fh1+fh2)=15 \cdot 30/(15+30)$) is as Zxr through linear approximation of measured values as shown in Fig. 21. Next, consider the imaginary components. Since the imaginary components are substantially proportional to the frequency component, the leakage inductance is calculated in accordance with $L=Zxi/(2 \cdot \pi \cdot fh_1)$ using the values at $fh2$ (30 Hz), where $Zxi=Zxi2$ and $fh_1=fh2$. Here, $fh2$ is used because the voltage value becomes larger at a higher frequency, resulting in a reduction in measurement error. The lower frequency may be used, or the leakage inductance may be calculated from the slope at two frequencies.

[0076] Next, a fifteenth embodiment will be described. In the measurement of the secondary resistance and leakage inductance, the previously determined voltage offset value v_{ref0} is used to calculate $Zx1$ and $Zx2$ by the following equations:

$$Zx1 = (v_{ref_ave1}/\sqrt{3}-v_{ref0})/(i_{fb_ave1}),$$

$$Zx2 = (v_{ref_ave2}/\sqrt{3}-v_{ref0})/(i_{fb_ave2})$$

[0077] The subsequent calculations are similar to the foregoing.

[0078] In the fourteenth embodiment, similar measurements are made at the same frequency as the foregoing and with application of current i_{fb2} different in magnitude from the current value fed during the measurement. Here, as an example, i_{fb2} is set to 40 % of the rated current of the motor (one half of the foregoing), and an average of the absolute value of the voltage command value at 15 Hz is set to v_{ref_ave3} ; an average of the absolute value of the detected current value at 15 Hz to i_{fb_ave3} ; and an average of the voltage command value at 30 Hz to v_{ref_ave4} ; and an average of the absolute value of the detected current value at 30 Hz to i_{fb_ave4} . As shown in Figs. 22(a), 22(b), linear approximation is made with two current values at 15Hz, 30 Hz, respectively, and the values at the current value equal to zero are derived as voltage offset v_{ofs15} at 15 Hz and voltage offset v_{ofs30} at 30 Hz. In another method, these offset values may be used for the voltage command values at 15 Hz, 30 Hz instead of voltage offset value v_{ref0} in the thirteenth embodiment to compensate for the voltage offset. Alternatively, rather than deriving the voltage offset values, the impedances may be calculated at 15 Hz, 30Hz, respectively, from the slope when the current value is changed. Also, an average value of two current values may be used for the phase to calculate a real part and an imaginary part of the impedance.

[0079] Though description has been omitted in the foregoing processing for simplification, the voltage values and

current values when the signals at 15 Hz, 30 Hz are applied are passed through low pass filters for averaging, after their absolute values are taken, and therefore they are averages. On the other hand, voltage value offset value v_{ref0} described in the embodiment of claim 13 is derived from a DC value and therefore is an effective value or a maximum value, so that v_{ref0} is converted to an average which is used. While the average is used herein, any of the effective value, average, maximum value may be used as long as the conversion associated therewith is consistent.

[0080] Fig. 23 is a block diagram illustrating the configuration of an apparatus for implementing a method of measuring a motor constant for an induction motor in a sixteenth and a seventeenth embodiment of the present invention. In Fig. 23, power converter 2 converts voltage command v_{ref} and voltage phase θ_v applied from motor constant calculator 1 to three-phase AC power which is supplied to induction motor 3. The values of currents flowing into induction motor 3 are captured as current i_u detected by current detector 4 for U-phase and current i_v detected by current detector 5 for v-phase. Coordinate converter 6 performs the calculations expressed by Equations (1) and (2) to convert i_u and i_v to two-phase AC currents i_α and i_β .

[0081] In Equation (2), the multiplication by (2/3) is intended for equaling the magnitude of the amplitude before and after the conversion. The phases at which the currents are detected are not limited to a combination of the U-phase and v-phase, but the currents may be detected at arbitrary two phases or at all the three phases. Two-phase AC currents i_α and i_β are fed to motor constant calculator 1 which calculates detected primary current value i_1 as a square root of the sum of squared two-phase AC currents i_α , i_β .

[0082] Fig. 23 shows an inverter-based motor driving apparatus from which parts required for practicing the present invention are extracted, wherein blocks such as velocity control, current control and the like disposed prior to voltage command and output voltage phase are replaced by motor constant calculator 1 during a normal operation in a conventional method of identifying a motor constant. Both are switched by an additional switch.

[0083] First, description will be made on the principle of an embodiment of claim 16.

[0084] Fig. 24 illustrates a T-1 type equivalent circuit per phase in an inoperative induction motor (slippage $s=1$). R_1 represents a primary resistance; L a leakage inductance; R_2 a secondary resistance; M a mutual inductance; v an applied voltage; i_1 a primary current of the motor; i_2 a secondary current of the motor; and i_m a current (excited current) flowing through mutual inductance M .

[0085] When an electromotive force generated by a change in the current flowing through mutual conductance M is represented by e_m , equations based on Kirchhoff's law are established in the equivalent circuit of Fig. 24 as follows:

$$v = R_1 \cdot i_1 + L \frac{di_1}{dt} + e_m \quad (3)$$

$$e_m = M \frac{di_m}{dt} = R_2 \cdot i_2 \quad (4)$$

$$i_1 = i_m + i_2 \quad (5)$$

[0086] Since leakage inductance L is smaller than mutual inductance M , Equation (3) is transformed into:

$$v = R_1 \cdot i_1 + e_m \quad (6)$$

when leakage inductance L is ignored for simplification.

[0087] Also, from Equations (4) and (5):

$$i_1 = i_m + \frac{1}{R_2} \cdot M \cdot \frac{di_m}{dt} \quad (7)$$

[0088] Equations (4) and (7) are substituted into Equation (6) for integration:

$$v = R_1 \cdot i_m + \frac{M(R_1 + R_2)}{R_2} \cdot \frac{di_m}{dt} \quad (8)$$

when Equation (8) is solved for i_m with an initial condition of:

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$$i_{m0}=0 \text{ when } t=0 \quad (9)$$

$$i_m = \frac{v}{R_1} \cdot (1 - e^{-\frac{t}{\tau}}) \quad (10)$$

$$\tau = \frac{M(R_1 + R_2)}{R_1 \cdot R_2} \quad (11)$$

where τ is a time constant.

[0089] Thus,

$$M = \frac{R_1 \cdot R_2}{R_1 + R_2} \cdot \tau \quad (12)$$

is established. As time constant τ is determined from current i_m flowing through mutual inductance M and substituted into Equation (12), mutual conductance M can be calculated.

[0090] Description will be made on the principle of a seventeenth embodiment.

[0091] Current i_m flowing through mutual inductance M is a current which flows within the induction motor, so that it cannot be directly measured from the input terminal of the induction motor. Therefore, description will be next made on a method of estimating current i_m flowing through mutual inductance M .

[0092] From Equations (4) and (6):

$$i_2 = \frac{v - R_1 \cdot i_1}{R_2} \quad (13)$$

[0093] Substituting Equation (13) into Equation (5):

$$i_m = i_1 - i_2 = i_1 - \frac{v - R_1 \cdot i_1}{R_2} \quad (14)$$

[0094] Rearrangement of Equation (14) results in:

$$i_m = (1 + \frac{R_1}{R_2}) \cdot i_1 - \frac{v}{R_2} \quad (15)$$

[0095] In this way, i_m can be calculated in accordance with Equation (15) using voltage v applied to the motor, and primary current i_1 flowing into the motor. Then, time constant τ is determined from a change in this i_m , and substituted into Equation (12), whereby mutual inductance M can be calculated.

[0096] No-load current i_0 is a current which flows when the induction motor is applied with the power at the rated voltage and rated frequency and rotated without load, in which case an equivalent circuit is represented by a series circuit of R_1 , L , M in the form of T-1 type equivalent circuit in Fig. 24.

[0097] Therefore, the relationship between voltage v and current i_1 in this event is expressed by:

$$v = R_1 \cdot i_1 + j\omega(L+M) \cdot i_1 \quad (16)$$

$$\omega = 2\pi f, \text{ where } f \text{ is the frequency of the power} \quad (17)$$

[0098] Equation (16) is rewritten only with attention paid to the magnitudes of the voltage and current to derive the rated voltage V :

$$V = \sqrt{R_1^2 + \omega^2 (L+M)^2} \cdot i_0 \quad (18)$$

[0099] V, I are values indicative of the magnitudes of the voltage and current, respectively, and may be any of effective values, maximum values or averages as long as the same one is employed for the voltage and current.

[0100] When Equation (18) is solved for I0:

$$I_0 = \frac{V}{\sqrt{R_1^2 + \omega^2 (L + M)^2}} \quad (19)$$

no-load current I0 is calculated.

[0101] Although R1 and L are taken into consideration in Equations (16), (18), (19), R1 and L may be ignored for simplification.

[0102] Fig. 25 shows the waveform of a change over time of estimate \hat{I}_m of I_m calculated in accordance with Equation (15) using primary current I_1 when voltage v equal to V_1 is applied stepwise, current I_m flowing through mutual inductance, primary current i_1 , and R_1 , R_2 . $I_{1\infty}$ to which i_1 , i_m , \hat{I}_m converge is (V_1/R_1) , and the waveform of \hat{I}_m changing from 0 to $I_{1\infty}$ can be confirmed to substantially match the waveform of I_m . Therefore, time constant $\hat{\tau}_m$ may be determined from a change in I_m at this time.

[0103] Now, contents of a method implemented on the basis of the foregoing principle will be described with reference to Fig. 23.

[0104] The following description will be made on the assumption that the current at the U-phase reaches a peak at phase of 0°.

[0105] In this embodiment, voltage phase θ_v was set at 0° for implementation.

[0106] First, description will be made on a method of determining the magnitude of predetermined voltage V_1 applied to motor 3. While voltage V_1 applied to motor 3 may be at an arbitrary value, voltage V_1 must actually be limited within a range in which induction motor 3 is not damaged by heat generated by the current. Therefore, description on the method of determining V_1 will be made herein in an example in which voltage V_1 is applied such that a resulting current value reaches 50 % of the rated current of the motor. First, voltage command v_{ref} at zero is applied, and v_{ref} is increased in increments of 1/1000 of the rated voltage of the induction motor while detected current value I_1 is measured. Then, at the time detected current value I_1 reaches 50 % of the rated current of the induction motor, the value of v_{ref} at this time is stored as V_1 , and the power supplied to motor 3 is shut off. The increment for the voltage command may be arbitrarily set at such a magnitude that does not cause a sudden change in the current. When a current controller is provided, 50 % of the rated current is applied as the current command. Then, at the time the detected current value matches the current command value, the current command value at this time may be set to V_1 . When the primary resistance is measured with a DC current applied therefor before identification of the mutual inductance or no-load current described in the present invention, a current value and a voltage command value at that time may be used. Of course, the current value may be set at a value other than 50 % of the rated current.

[0107] Next, V_1 is applied as voltage command v_{ref} , and induction motor 3 is applied with a voltage stepwise. Primary current I_1 is measured at this time, and \hat{I}_m is calculated in accordance with the aforementioned Equation (15). Here, in Equation (15), v corresponds to v_{ref} , and I_m to \hat{I}_m . Values used for R_1 , R_2 are given by a test result table of the induction motor or another existent identifying means.

[0108] Time constant τ is determined from the waveform of rising \hat{I}_m , and the value at this time is designated by $\hat{\tau}_{I_m}$. $\hat{\tau}_{I_m}$ is substituted into τ shown in Equation (12) to calculate mutual inductance M . While time constant $\hat{\tau}_m$ is generally determined by measuring a time for \hat{I}_m to reach from zero to a final (convergence) value $(1-1/e) \approx 0.632$, measurements may be made on a change in the current at an arbitrary current value and on a time during the change, and conversion may be made to match this time with the time constant. In the latter case, measurements can be made at a plurality of points, thereby making it possible to reduce variations by measuring several data and averaging the data.

[0109] A seventeenth embodiment will be described.

[0110] Since rated voltage V_{rate} and rated frequency f_{rate} of the induction motor are given in the specifications of the induction motor, no-load current I_0 is calculated by substituting rated voltage V_{rate} and rated frequency f_{rate} , R_1 , L , R_2 given by the test result table of the induction motor or another existent identifying means, and M identified by the aforementioned method into Equation (19):

$$I_0 = \frac{V_{rate}}{\sqrt{R_1^2 + (2\pi f_{rate})^2 (L + M)^2}} \quad (20)$$

[0111] When an error is tolerable to some degree, L and R_1 may be omitted in the calculation for simplification.

[0112] Next, an eighteenth embodiment will be described.

[0113] As discussed above, when a DC current is applied, the equivalent circuit of the induction motor can be re-

garded as having only the primary resistance. Therefore, although the DC current transiently flows into the secondary resistance immediately after the DC current is applied, the primary resistance alone exists when a sufficient time has elapsed, so that the voltage is given by:

$$v = R1 \cdot i1_{\infty}$$

where $i1_{\infty}$ represents a current value to which primary current value $i1$ converges. The aforementioned Equation (15) can be rewritten to:

$$i_m = i1 - \frac{R1}{R2} (i1_{\infty} - i1) \quad (21)$$

[0114] Here, because of an estimate, i_m is described as \hat{i}_m . Subsequently, a calculation is made in a manner similar to the aforementioned sixteenth embodiment. In doing so, since no-voltage value is used in the calculation, the measurement can be made independently of a voltage accuracy of the driving apparatus. When a value upon measurement of the primary resistance is used in applying the voltage command as described above, the value used for $i1_{\infty}$ may be a current value which is read upon measurement of the resistance.

[0115] A nineteenth embodiment carries out the seventeenth embodiment using the method of calculating \hat{i}_m in the eighteenth embodiment.

Claims

1. A method of measuring a motor constant for an induction motor in a motor vector control apparatus having a d-axis current proportional-plus-Integral controller which receives a current command for a d-axis component of a primary current of the motor and a detected current value of the d-axis component for controlling a deviation between both to reduce to zero; a first adder for adding an output of said proportional-plus-integral controller and an arbitrary d-axis auxiliary voltage command value to derive a d-axis voltage command value; a q-axis current proportional-plus-integral controller which receives a current command for a q-axis component of the primary current of the motor and a detected current value of the q-axis component for controlling a deviation between both to reduce to zero; a second adder for adding an output of said proportional-plus-integral controller and an arbitrary q-axis auxiliary voltage command value to derive a q-axis voltage command value; and a power converter for calculating a magnitude v_{ref} and a voltage phase θ_v of a voltage command from the d-axis voltage command value and the q-axis voltage command value, and converting a DC current to a three-phase AC current based on the magnitude of the voltage command and the phase of the voltage command to output the three-phase AC current, said vector control apparatus being configured to convert the motor to an equivalent circuit of a three-phase Y (star) connection for handling and controlling the motor, said method comprising the steps of:

applying a d-axis current command value i_{d_ref1} and a q-axis current command value i_{q_ref1} previously set at arbitrary fixed values as first command values, and applying the d-axis auxiliary voltage command vd_ref_c and the q-axis auxiliary voltage command value vq_ref_c both set at zero to operate said vector control apparatus;

after the lapse of a previously set first time, setting a proportional gain of the d-axis proportional-plus-integral controller and a proportional gain of the q-axis proportional-plus-integral controller to zero, and after the lapse of a previously set second time from this time, creating the voltage command:

$$v_{ref} = \sqrt{(vd_ref^2 + vq_ref^2)}$$

from the d-axis voltage command vd_ref and the q-axis voltage command vq_ref , and creating the detected current value:

$$I_{fb} = \sqrt{(Id_fb^2 + Iq_fb^2)}$$

from the d-axis detected current value Id_fb and the q-axis detected current value Iq_fb ;
setting an average of v_{ref} and an average of I_{fb} recorded within an arbitrary time during the second time

as first data v_{ref1} , i_{fb1} , respectively;
 returning the gains of both said proportional-plus-Integral controllers to original values, applying a d-axis current command value i_{d_ref2} and a q-axis current command value i_{q_ref2} previously set at arbitrary fixed values as second command values, and applying the d-axis auxiliary voltage command value $v_{d_ref_c}$ and the q-axis auxiliary voltage command value $v_{q_ref_c}$ set at zero to operate said vector control apparatus;
 after the lapse of the previously set first time, setting the proportional gain of the d-axis proportional-plus-integral controller and the proportional gain of the q-axis proportional-plus-integral controller to zero, and after the lapse of a previously set second time from this time, calculating a primary resistance of the motor in accordance with:

$$R1 = \{(v_{ref2} - v_{ref1}) / \sqrt{3}\} / (i_{fb2} - i_{fb1})$$

using an average of v_{ref} and an average of i_{fb} stored within an arbitrary time during the second time as second data v_{ref2} , i_{fb2} , respectively, and calculating a line-to-line resistance value of the motor in accordance with $R_{L-L} = 2 \cdot R1$.

2. The method according to claim 1, including, after the lapse of the first time:

setting the output of the d-axis current proportional-plus-Integral controller to the d-axis auxiliary voltage command value, and simultaneously setting the proportional gain and Integral gain of the d-axis current proportional-plus-Integral controller and the output of the d-axis current proportional-plus-Integral controller to zero;
 setting the output of the q-axis current proportional-plus-Integral controller to the q-axis auxiliary voltage command value, and simultaneously setting the proportional gain and Integral gain of the q-axis current proportional-plus-Integral controller and the output of the q-axis current proportional-plus-Integral controller to zero;
 and
 performing the operation after the lapse of said first time in a similar manner.

3. The method according to claim 1 or 2, wherein three or more levels are provided for the d-axis current command value and the q-axis current command value previously set at arbitrary fixed values, and the primary resistance is calculated as an average of the values of the primary resistance calculated in respective intervals.

4. A method of measuring a motor constant for an induction motor in a motor vector control apparatus having a d-axis current proportional-plus-Integral controller which receives a current command for a d-axis component of a primary current of the motor and a detected current value of the d-axis component for controlling a deviation between both to reduce to zero; a first adder for adding an output of said proportional-plus-Integration controller and an arbitrary d-axis auxiliary voltage command value to derive a d-axis voltage command value; a q-axis current proportional-plus-Integral controller which receives a current command for a q-axis component of the primary current of the motor and a detected current value of the q-axis component for controlling a deviation between both to reduce to zero; a second adder for adding an output of said proportional-plus-Integral controller and an arbitrary q-axis auxiliary voltage command value to derive a q-axis voltage command value; and a power converter for calculating a magnitude v_{ref} and a voltage phase θ_v of a voltage command from the d-axis voltage command value and the q-axis voltage command value, and converting a DC current to a three-phase AC current based on the magnitude of the voltage command and the phase of the voltage command to output the three-phase AC current, said vector control apparatus being configured to convert the motor to an equivalent circuit of a three-phase Y (star) connection for handling and controlling the motor, said method comprising the steps of:

setting gains and outputs of both said proportional-plus-Integral controllers, the d-axis auxiliary voltage command and the q-axis auxiliary voltage command to zero, setting a voltage phase θ_v to a previously set arbitrary fixed value, and giving a magnitude v_{ref} of the voltage command by $v_{ref} = v_{amp} \cdot \sin(2 \cdot \pi \cdot f_h \cdot t)$, where f_h is a frequency 1/10 or more as high as a rated operation frequency of the motor, and v_{amp} is a voltage amplitude; incrementally or decrementally adjusting v_{amp} while monitoring a current value i_{fb} such that:

$$i_{fb} = \sqrt{(i_{d_fb}^2 + i_{q_fb}^2)}$$

calculated from a d-axis detected current value i_{d_fb} and a q-axis detected current value i_{q_fb} reaches a previously arbitrarily set first set current value;

after i_{fb} reaches said first set current value, setting an average of an absolute value of the magnitude v_{ref} of the voltage command to v_{ref_ave1} , an average of an absolute value of the magnitude of the detected current value i_{fb} to i_{fb_ave1} , and the phase of i_{fb} with respect to v_{ref} θ_{dif1} after the lapse of an arbitrarily set time;

adjusting v_{amp} to reach a previously set second set current value, and setting the average of the absolute value of the magnitude v_{ref} of the current command to v_{ref_ave2} , the average of the absolute value of the magnitude of the detected current value i_{fb} to i_{fb_ave2} , and the phase of i_{fb} with respect to v_{ref} to θ_{dif2} after the lapse of said set time;

calculating:

$$Z_x = \{v_{ref_ave2} - v_{ref_ave1}\} / \sqrt{3} / (i_{fb_ave2} - i_{fb_ave1}), \theta_{dif_L} = (\theta_{dif1} + \theta_{dif2}) / 2$$

$$Z_{x_r} = Z_x \cdot \cos \theta_{dif_L}, Z_{x_i} = Z_x \cdot \sin \theta_{dif_L},$$

and

from this, calculating a secondary resistance of the motor in accordance with $R2 = Z_{x_r} - R1$, and a leakage inductance in accordance with $L = Z_{x_i} / (2 \cdot \pi \cdot f_h)$.

5. The method according to claim 4, including adding a DC offset component v_{ref_ofs} to the voltage command value to apply the voltage command expressed by $v_{ref} = v_{amp} \cdot \sin(2 \cdot \pi \cdot f_h \cdot t) + v_{ref_ofs}$, feeding the detected current value i_{fb} to a high pass filter designed to filter out a DC component and pass a signal having an f_h component there-through to use an output of the high pass filter as new i_{fb} , feeding v_{ref} to a high pass filter having the same characteristics as that used for i_{fb} in a similar manner, and calculating the secondary resistance $R2$ and the leakage inductance L of the motor in accordance with said equation using the output of the high pass filter as new v_{ref} .

6. The method according to claim 5, including calculating the primary resistance:

$$R1 = \{v_{ref_dc2} - v_{ref_dc1}\} / \sqrt{3} / (i_{fb_dc2} - i_{fb_dc1})$$

using an average v_{ref_dc1} of the voltage command v_{ref} and an average i_{fb_dc1} of the detected current value i_{fb} at the first set current value before the detected current value i_{fb} is fed to the high pass filter, and an average v_{ref_dc2} of the voltage command v_{ref} and an average i_{fb_dc2} of the detected current value i_{fb} at the second set current value before the detected current value i_{fb} is fed to the high pass filter, and calculating the secondary resistance $R2$ using the first resistance value.

7. A method of measuring a motor constant for an induction motor in a motor vector control apparatus having a d-axis current proportional-plus-integral controller which receives a current command for a d-axis component of a primary current of the motor and a detected current value of the d-axis component for controlling a deviation between both to reduce to zero; a first adder for adding an output of said proportional-plus-integration controller and an arbitrary d-axis auxiliary voltage command value to derive a d-axis voltage command value; a q-axis current proportional-plus-integral controller which receives a current command for a q-axis component of the primary current of the motor and a detected current value of the q-axis component for controlling a deviation between both to reduce to zero; a second adder for adding an output of said proportional-plus-integral controller and an arbitrary q-axis auxiliary voltage command value to derive a q-axis voltage command value; and a power converter for calculating a magnitude v_{ref} and a voltage phase θ_v of a voltage command from the d-axis voltage command value and the q-axis voltage command value, and converting a DC current to a three-phase AC current based on the magnitude of the voltage command and the phase of the voltage command to output the three-phase AC current, said vector control apparatus being configured to convert the motor to an equivalent circuit of a three-phase Y (star) connection for handling and controlling the motor, said method comprising the steps of:

setting gains and outputs of both said proportional-plus-integral controllers, the d-axis auxiliary voltage command and the q-axis auxiliary voltage command to zero, setting a voltage phase θ_v to a previously set arbitrary fixed value, and giving a magnitude v_{ref} of the voltage command by $v_{ref} = v_{amp} \cdot \sin(2 \cdot \pi \cdot f_l \cdot t)$, where f_l is a frequency 1/5 or less as high as a rated operation frequency of the motor, and v_{amp} is a voltage amplitude; incrementally or decrementally adjusting v_{amp} while monitoring a current value i_{fb} such that:

$$i_{fb} = \sqrt{(i_{d_fb}^2 + i_{q_fb}^2)}$$

calculated from a d-axis detected current value i_{d_fb} and a q-axis detected current value i_{q_fb} reaches a previously arbitrarily set first set current value;

after i_{fb} reaches said first set current value, setting an average of an absolute value of the magnitude v_{ref} of the voltage command to v_{ref_ave3} , an average of an absolute value of the magnitude of the detected current value i_{fb} to i_{fb_ave3} , and the phase of i_{fb} with respect to v_{ref} to θ_{dif3} after the lapse of a first arbitrary set time;

adjusting v_{amp} to reach a previously set second set current value, and setting the average of the absolute value of the magnitude v_{ref} of the current command to v_{ref_ave4} , the average of the absolute value of the magnitude of the detected current value i_{fb} to i_{fb_ave4} , and the phase of i_{fb} with respect to v_{ref} to θ_{dif4} after the lapse of said first set time;

calculating:

$$Z_{x2} = (v_{ref_ave4} - v_{ref_ave3}) / \sqrt{3} / (i_{fb_ave4} - i_{fb_ave3}), \theta_{dif_m} = (\theta_{dif3} + \theta_{dif4}) / 2$$

$$Z_{x_r2} = Z_{x_m} \cos \theta_{dif_m}, \text{ and}$$

from this, calculating a mutual inductance of the motor in accordance with:

$$M = \frac{R_2}{2 \cdot \pi \cdot f_1} \cdot \frac{Z_{x_r2} - R_1}{\sqrt{R_1^2 + R_2^2 - Z_{x_r2}^2}}$$

8. The method according to claim 7, including adding a DC offset component v_{ref_ofs} to the voltage command value to apply the voltage command expressed by $v_{ref} = v_{amp} \cdot \sin(2 \cdot \pi \cdot f_1 \cdot t) + v_{ref_ofs}$, feeding the detected current value i_{fb} to a high pass filter designed to filter out a DC component and pass a signal having an fh component there-through to use an output of the high pass filter as new i_{fb} , feeding v_{ref} to a high pass filter having the same characteristics as that used for i_{fb} in a similar manner, and calculating the mutual inductance M of the motor in accordance with said calculation equation using the output of the high pass filter as new v_{ref} .

9. The method according to claim 8, including calculating the primary resistance:

$$R_1 = (v_{ref_dc2} - v_{ref_dc1}) / \sqrt{3} / (i_{fb_dc2} - i_{fb_dc1})$$

using an average v_{ref_dc1} of the voltage command v_{ref} and an average i_{fb_dc1} of the detected current value i_{fb} at the first set current value before the detected current value i_{fb} is fed to the high pass filter, and an average v_{ref_dc2} of the voltage command v_{ref} and an average i_{fb_dc2} of the detected current value i_{fb} at the second set current value before the detected current value i_{fb} is fed to the high pass filter, and calculating the secondary resistance R_2 using the first resistance value.

10. A method of measuring a motor constant for an induction motor in a motor control apparatus having a d-axis current proportional-plus-integral controller which receives a current command for a d-axis component of a primary current of the motor and a detected current value of the d-axis component for controlling a deviation between both to reduce to zero; a q-axis current proportional-plus-integral controller which receives a current command for a q-axis component of the primary current of the motor and a detected current value of the q-axis component for controlling a deviation between both to reduce to zero; and a power converter for calculating a magnitude v_{ref} and a voltage phase v of a voltage command from the d-axis voltage command value which is an output of said d-axis current proportional-plus-integral controller and the q-axis voltage command value which is an output of said q-axis current proportional-plus-integral controller, and converting a DC current to a three-phase AC current based on the magnitude of the voltage command and the phase of the voltage command to output the three-phase AC current, said vector control apparatus being configured to control the d-axis current command and the q-axis current command to operate the motor in conformity with an arbitrary velocity command, said method comprising the step of:

calculating:

$$V_{q\bar{q}} = \frac{v_{q_ref}}{\sqrt{3}} - R1 \cdot i_{q_fb} - 2\pi \cdot f_{phi} \cdot L \cdot i_{d_fb}$$

$$V_{q\bar{q}} = \frac{v_{q_ref}}{\sqrt{3}} - R1 \cdot i_{d_fb} - 2\pi \cdot f_{phi} \cdot L \cdot i_{q_fb}$$

$$Q = V_{q\bar{q}} \cdot i_{d_fb} - V_{q\bar{q}} \cdot i_{q_fb}$$

$$E = \sqrt{V_{q\bar{q}}^2 + V_{d\bar{d}}^2}$$

$$M = \frac{E^2}{2\pi \cdot f_{phi} \cdot Q}$$

$$I_0 = \frac{V_{base} / \sqrt{3}}{2\pi \cdot f_{base} (M + L)}$$

at an arbitrary time when the motor is operated in an arbitrary load condition at an arbitrary velocity, using an output frequency f_{phi} ; the d-axis voltage command v_{d_ref} ; the q-axis voltage command v_{q_ref} ; a d-axis detected current value i_{d_fb} ; a q-axis detected current value i_{q_fb} ; and a base voltage v_{base} , a base frequency f_{base} , a primary resistance value $R1$ and a leakage inductance L of the motor, thereby determining both or one of a mutual inductance M and a no-load current I_0 of the motor.

11. A method of measuring a motor constant for an induction motor in a motor control apparatus configured to supply a three-phase AC current to the induction motor through an inverter to operate the motor at a variable velocity, said motor control apparatus having a current detector for detecting the current flowing at two arbitrary phases or three phases of an inverter output; a proportional-plus-integral controller which receives a current command value for a primary current fed to the motor, and a primary current value i_{fb} of a primary current detector derived from a current value detected by said current detector to control an output voltage command value v_{ref} such that a deviation between both reduces to zero; and a power converter for outputting a three-phase AC current based on the voltage command value v_{ref} and a voltage output phase θ_v , said motor control apparatus being configured to convert the motor to an equivalent circuit of a three-phase Y (star) connection for handling the equivalent circuit, said method comprising the steps of:

operating said proportional-plus-integral controller by setting a previously set arbitrary phase to the voltage output phase θ_v , and applying a current command value i_{ref1} previously set at an arbitrary fixed value as a first command value;

after the lapse of a previously set first time, setting a proportional gain of said proportional-plus-integral controller to zero, and after the lapse of a previously set second time from this time, setting an average of v_{ref} and an average of i_{fb} within an arbitrary time during the second time to first data v_{ref1} , i_{fb1} , respectively; operating said proportional-plus-integral controller by returning the gain of said proportional-plus-integral controller to an original value, and applying a current command value i_{ref2} previously set at an arbitrary fixed value as a second command value;

after the lapse of the previously set first time, setting the proportional gain of said proportional-plus-integral controller to zero, and after the lapse of a previously set second time from this time, setting an average of v_{ref} and an average of i_{fb} recorded within an arbitrary time during the second time to second data v_{ref2} , i_{fb2} , respectively; and

calculating a primary resistance $R1$ of the motor in accordance with:

$$R1 = \{(v_{ref2} - v_{ref1}) / \sqrt{3}\} / (i_{fb2} - i_{fb1})$$

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and calculating a line-to-line resistance value of the motor in accordance with $R_{L-L}=2 \cdot R_1$.

12. The method according to claim 11, wherein three or more levels are provided for the current command value previously set at the arbitrary fixed value, and the primary resistance value is calculated as an average of the values of the primary resistance calculated in respective intervals.

13. The method according to claim 11, wherein the current command value v_{ref0} when the detected current value i_{fb} is zero is calculated from a linear equation derived from the measured values v_{ref1} , i_{fb1} , v_{ref2} and i_{fb2} , and set to a voltage offset value.

14. A method of measuring a motor constant for an induction motor in a motor control apparatus configured to supply three-phase AC to the induction motor through an inverter to operate the motor at a variable velocity, said motor control apparatus having current detectors disposed in two arbitrary phases or three phases of an inverter output, a proportional-plus-integral controller which receives a current command value for a primary current fed to the motor, and a primary current value i_{fb} of a primary current detector derived from current values detected by said current detectors to control an output voltage command value v_{ref} such that a deviation between both reduces to zero; and a power converter for outputting a three-phase AC current based on the voltage command value v_{ref} and a voltage output phase θ_v , said motor control apparatus being configured to convert the motor to an equivalent circuit of a three-phase Y (star) connection for handling the equivalent circuit, said method comprising the steps of:

setting the voltage phase θ_v at a previously set arbitrary fixed value, and giving a magnitude v_{ref} of a voltage command by $v_{ref}=v_{amp} \cdot \sin(2 \cdot \pi \cdot f_{h1} \cdot t)$, where f_{h1} is a frequency 1/10 or more as high as a base operation frequency of the motor, and v_{amp} is a voltage amplitude;

incrementally or decrementally adjusting v_{amp} while monitoring the detected current value i_{fb} such that i_{fb} reaches a previously arbitrarily set current value;

after i_{fb} reaches said set current value, setting an average of an absolute value of the magnitude v_{ref} of the voltage command to v_{ref_ave1} , an average of an absolute value of the magnitude of the detected current value i_{fb} to i_{fb_ave1} , and the phase of i_{fb} with respect to v_{ref} to θ_{dif1} after the lapse of an arbitrarily set time;

setting the frequency to a frequency f_{h2} 1/10 or more higher than the base operation frequency of the motor and different from f_{h1} , adjusting v_{amp} to reach said set current value, and after the lapse of said set time, setting the average of the absolute value of the magnitude v_{ref} of the current command to v_{ref_ave2} , the average of the absolute value of the magnitude of the detected current value i_{fb} to i_{fb_ave2} , and the phase of i_{fb} with respect to v_{ref} to θ_{dif_2} ;

calculating:

$$Zx1=(v_{ref_ave1}/\sqrt{3})/(i_{fb_ave1}), Zx2=(v_{ref_ave2}/\sqrt{3})/(i_{fb_ave2})$$

$$Zxr1 = Zx1 \cdot \cos \theta_{dif_1}, Zxr2 = Zx2 \cdot \cos \theta_{dif_2},$$

$$Zxi1 = Zx1 \cdot \sin \theta_{dif_1}, Zxi2 = Zx2 \cdot \sin \theta_{dif_2}$$

calculating the value of Zxr when the frequency f_h is at $f_{h1} \cdot f_{h2}/(f_{h1}+f_{h2})$ from a linear equation derived using $Zxr1$ when the frequency is at f_{h1} and $Zxr2$ when the frequency is at f_{h2} , and calculating a secondary resistance of the motor using the value of Zxr and the primary resistance R_1 of the motor in accordance with $R2=Zxr-R_1$; and

calculating a leakage inductance in accordance with $L=Zxi/(2 \cdot \pi \cdot f_{h_1})$, where f_{h_1} represents the higher frequency of f_{h1} and f_{h2} , and Zxi represents the value of Zxi at this time.

15. The method of measuring a motor constant for an induction motor according to claim 14, including:

establishing:

$$Zx1 = (v_{ref_ave1}/\sqrt{3}-v_{ref0})/(i_{fb_ave1}),$$

$$Z_{x2} = (v_ref_ave2 / \sqrt{3} - v_ref0) / (i_fb_ave2)$$

using the voltage offset value v_ref0 calculated in accordance with the method according to claim 13 to calculate a secondary resistance $R2$ and a leakage inductance L of the motor.

16. A method of measuring a motor constant for an induction motor in a motor control apparatus configured to supply a three-phase AC current to the induction motor through an inverter to operate the induction motor at a variable velocity, said motor control apparatus having a power converter for delivering a three-phase AC current based on an output voltage command value v_ref and a voltage output phase θ_v , and a current detector for detecting a primary current flowing into the induction motor, said motor control apparatus receiving a detected primary current value $i1$ derived from a current value detected by said current detector, said method comprising the steps of:

creating an equivalent circuit per phase of the induction motor in the form of T-1 type equivalent circuit; setting a previously set arbitrary fixed value to the voltage phase θ_v and a predetermined fixed value to the voltage command v_ref , reading the detected primary current value $i1$ flowing into the induction motor in this event, and estimating a current i_m flowing through a mutual inductance M in accordance with:

$$\hat{i}_m = \left(1 + \frac{R1}{R2}\right) \cdot i1 - \frac{v_ref}{R2}$$

using said primary current value $i1$ and a primary resistance value $R1$ and a secondary resistance value $R2$ given by an additional means; determining a time constant $\hat{\tau}_m$ from the waveform of the estimate $\hat{i}_m(t)$ of the rising current; and calculating the mutual inductance M in accordance with:

$$M = \frac{R1 \cdot R2}{R1 + R2} \cdot \hat{\tau}_m$$

17. The method of measuring a motor constant for an induction motor according to claim 16, including calculating a no-load current $i0$ using the mutual inductance M or the time constant $\hat{\tau}_m$, the primary resistance value $R1$, a leakage inductance L and the secondary resistance value $R2$ given by an additional means, a rated voltage V_{rate} and a rated frequency f_{rate} given as the rating of the motor, and said mutual inductance M .

18. A method of measuring a motor constant for an induction motor in a motor control apparatus configured to supply a three-phase AC current to the induction motor through an inverter to operate the induction motor at a variable velocity, said motor control apparatus having a power converter for delivering a three-phase AC current based on an output voltage command value v_ref and a voltage output phase θ_v , and a current detector for detecting a primary current flowing into the induction motor, said motor control apparatus receiving a detected primary current value $i1$ derived from a current value detected by said current detector, said method comprising the steps of:

creating an equivalent circuit per phase of the induction motor in the form of T-1 type equivalent circuit; setting a previously set arbitrary fixed value to the voltage phase θ_v and a predetermined fixed value to the voltage command v_ref , reading the detected primary current value $i1$ flowing into the induction motor in this event, and estimating a current i_m flowing through a mutual inductance M using said primary current value $i1$, and a primary resistance value $R1$ and a secondary resistance value $R2$ given by an additional means in accordance with:

$$\hat{i}_m = i1 - \frac{R1}{R2} (i1_{\infty} - i1)$$

where $i1_{\infty}$ represents a constant value to which the primary current value $i1$ converges when the voltage command v_ref is applied; determining a time constant $\hat{\tau}_m$ from the waveform of the estimate $\hat{i}_m(t)$ of the rising current; and calculating the mutual inductance M in accordance with:

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$$M = \frac{R1 \cdot R2}{R1 + R2} \cdot \hat{\tau}_{lm}$$

- 5 19. The method for an Induction motor according to claim 18, including calculating a no-load current I_0 using the calculated mutual Inductance M or the time constant $\hat{\tau}_{lm}$, the primary resistance value $R1$, a leakage Inductance L and the secondary resistance value $R2$ given by an additional means, a rated voltage V_{rate} and a rated frequency f_{rate} given as the rating of the motor, and said mutual Inductance M .

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Fig. 1

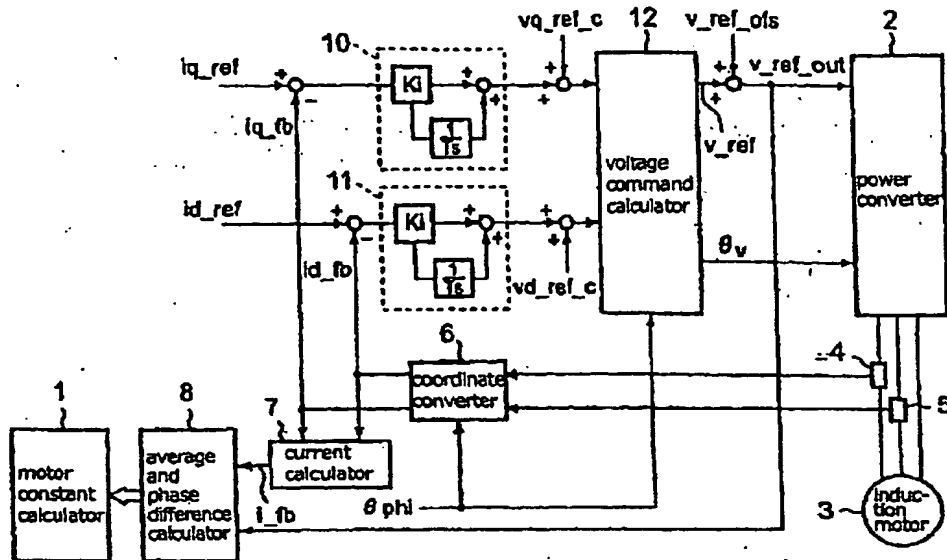


Fig. 2

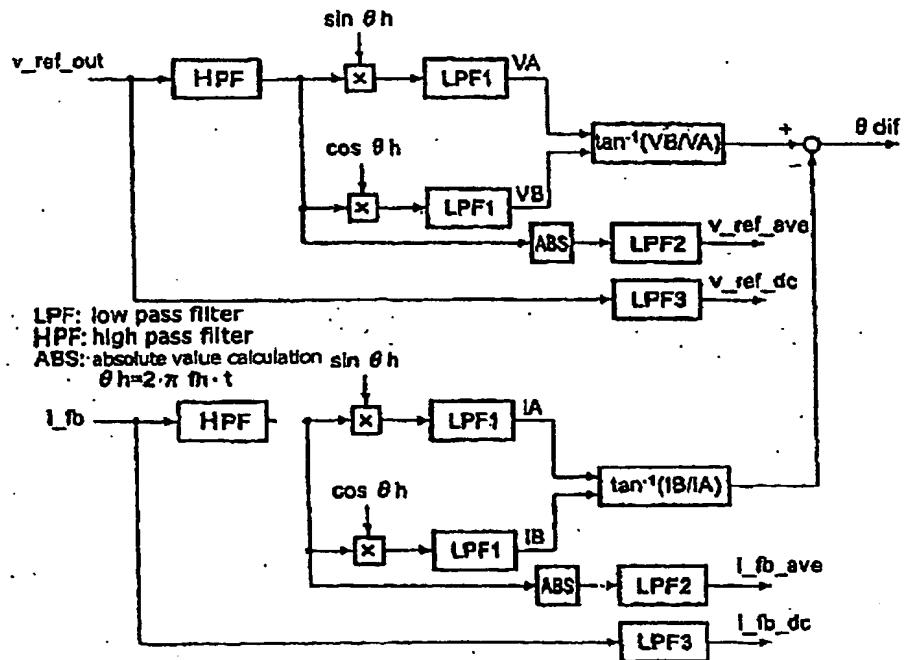


Fig. 3

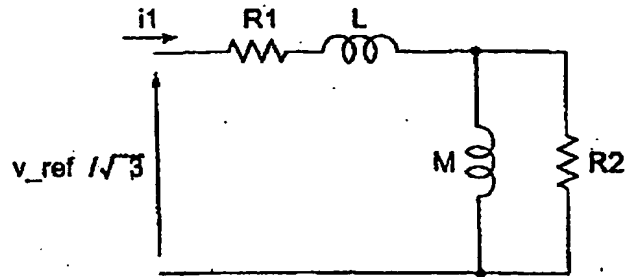


Fig. 4

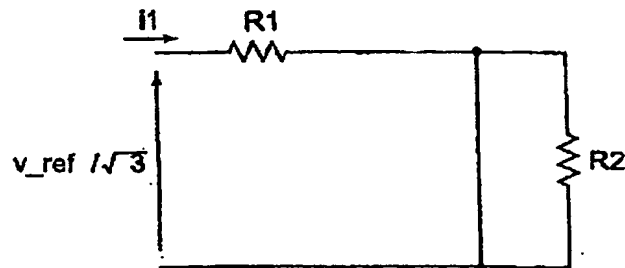


Fig. 5

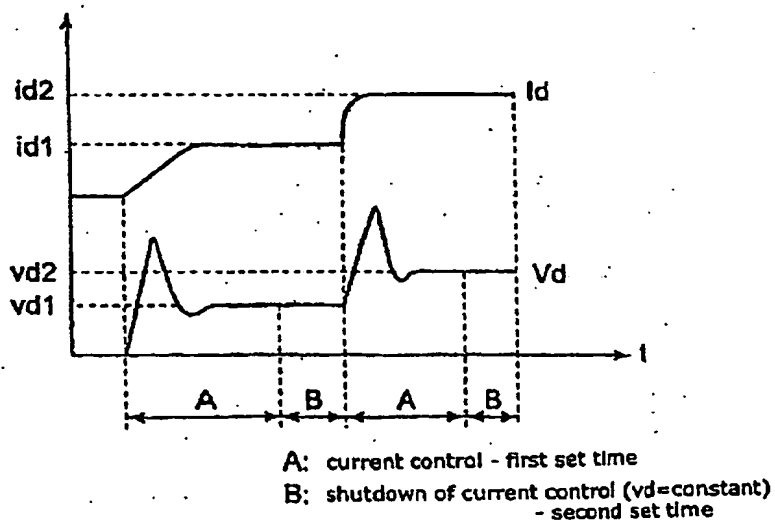


Fig. 6

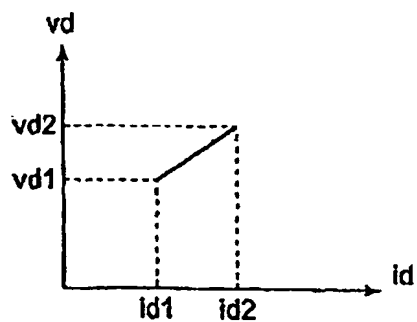


Fig. 7

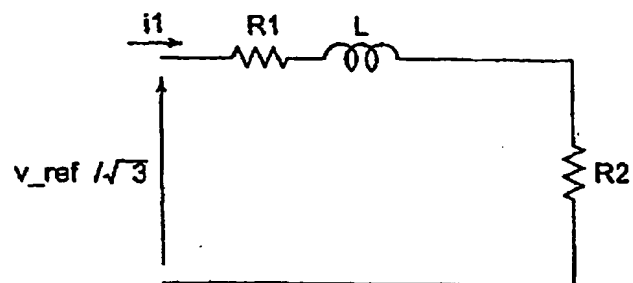


Fig. 8

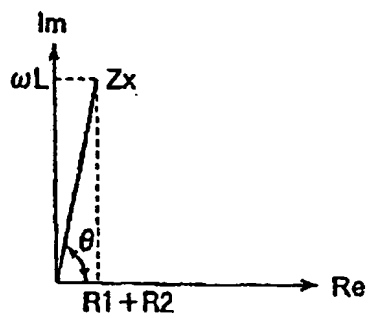


Fig. 9

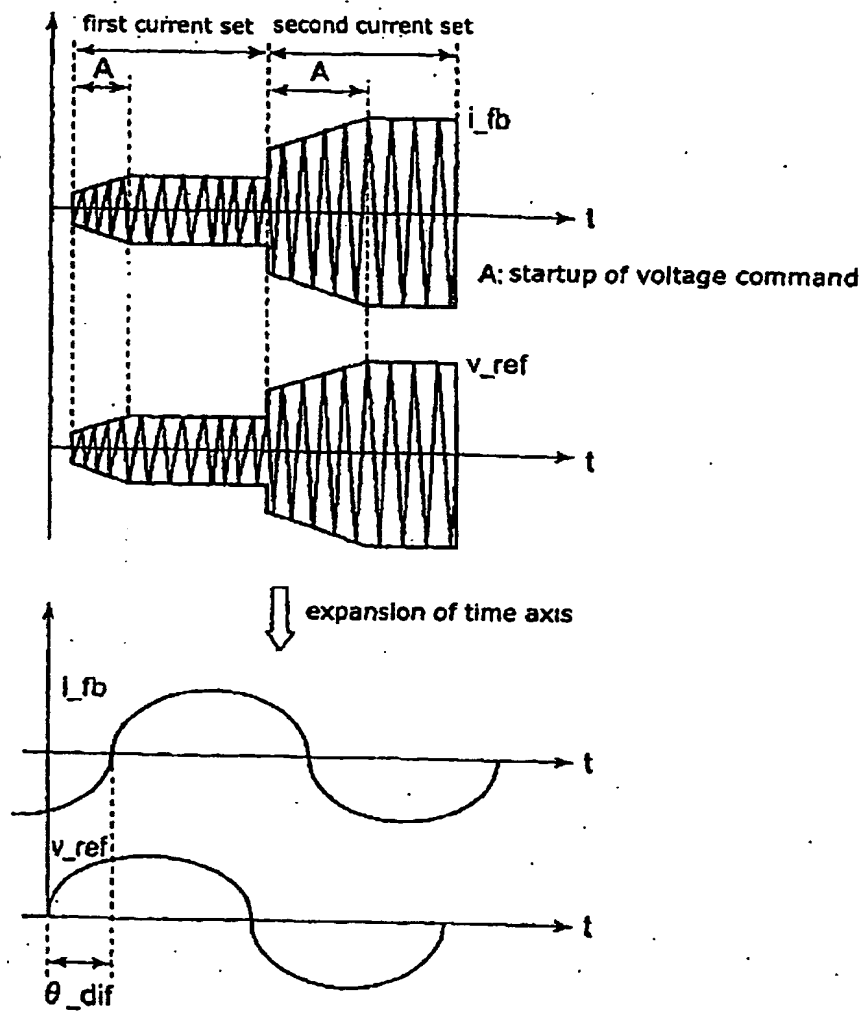


Fig. 10

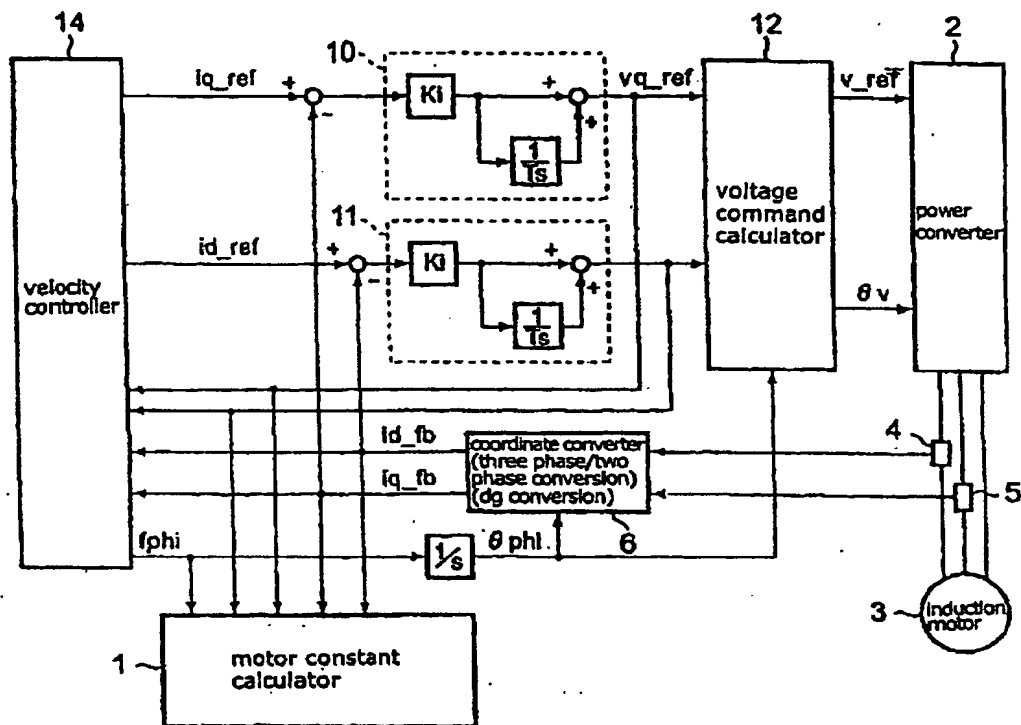


Fig. 11

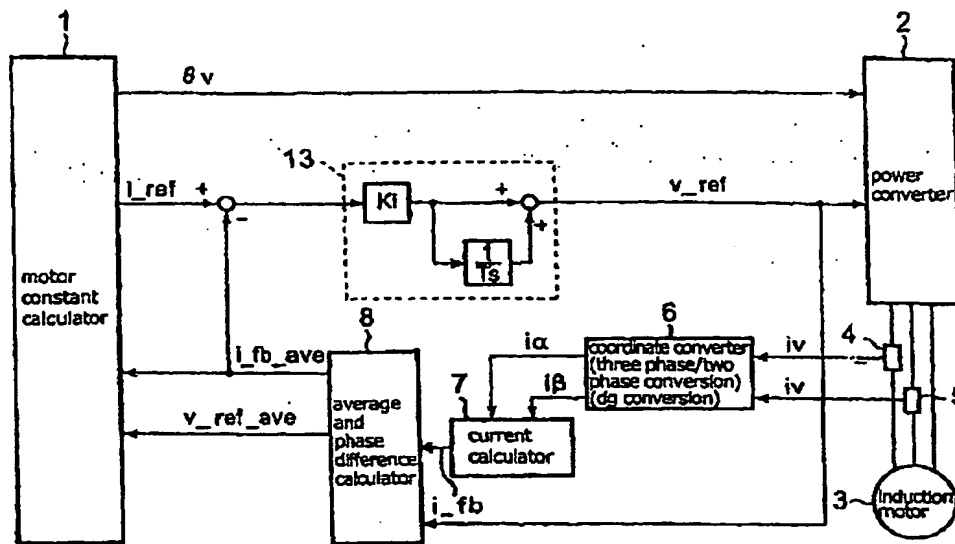


Fig. 12

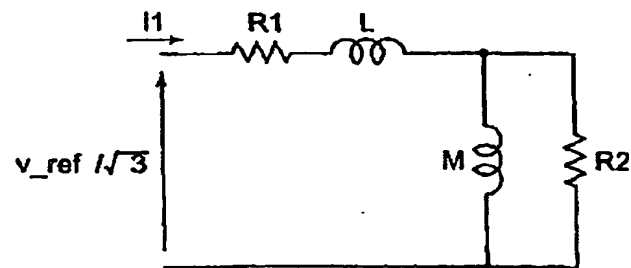


Fig. 13

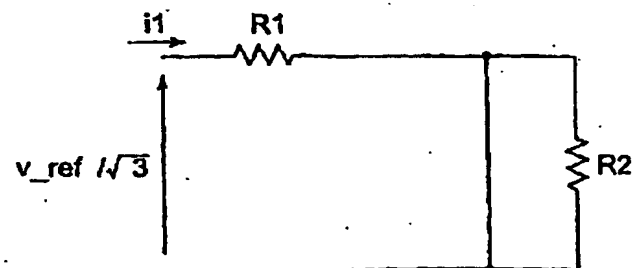


Fig. 14

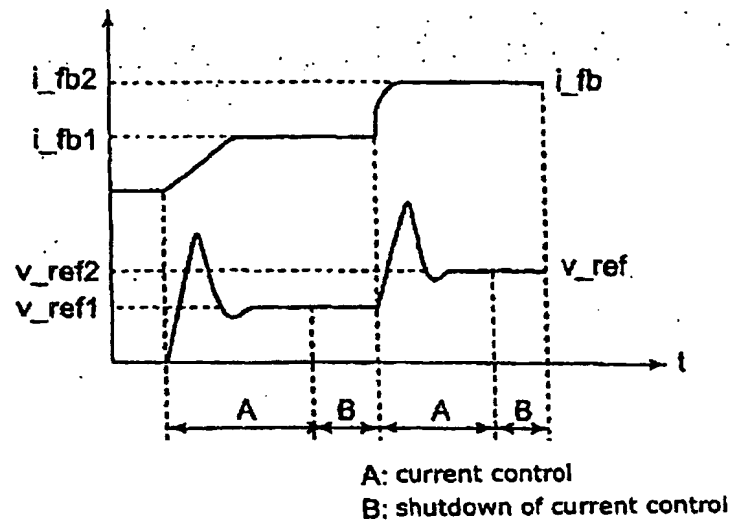


Fig. 15

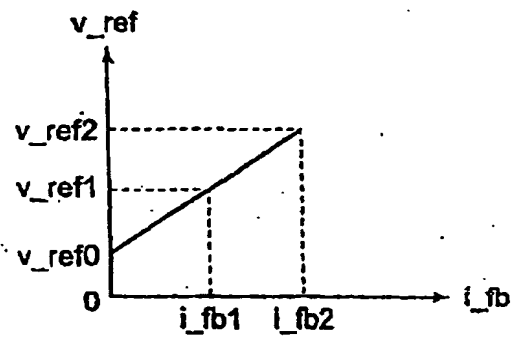


Fig. 16

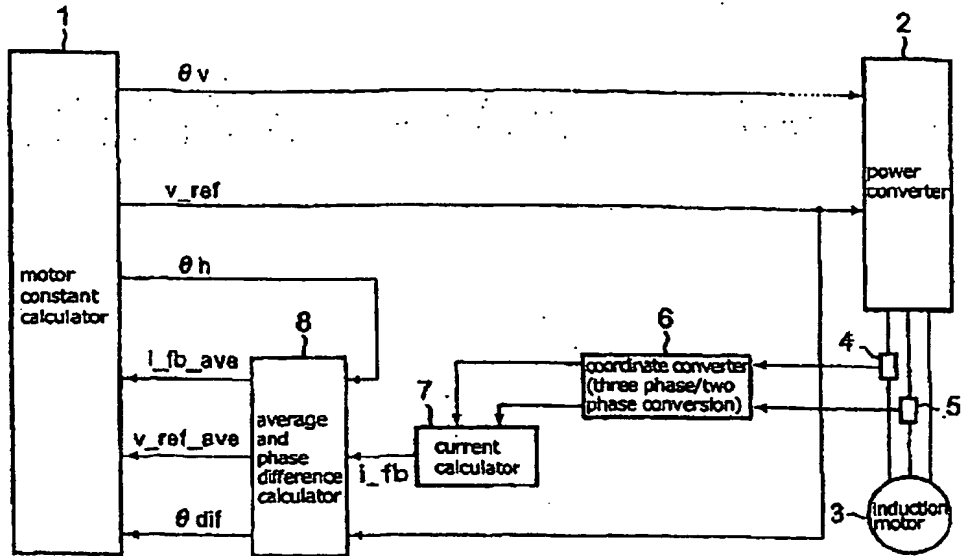


Fig. 17

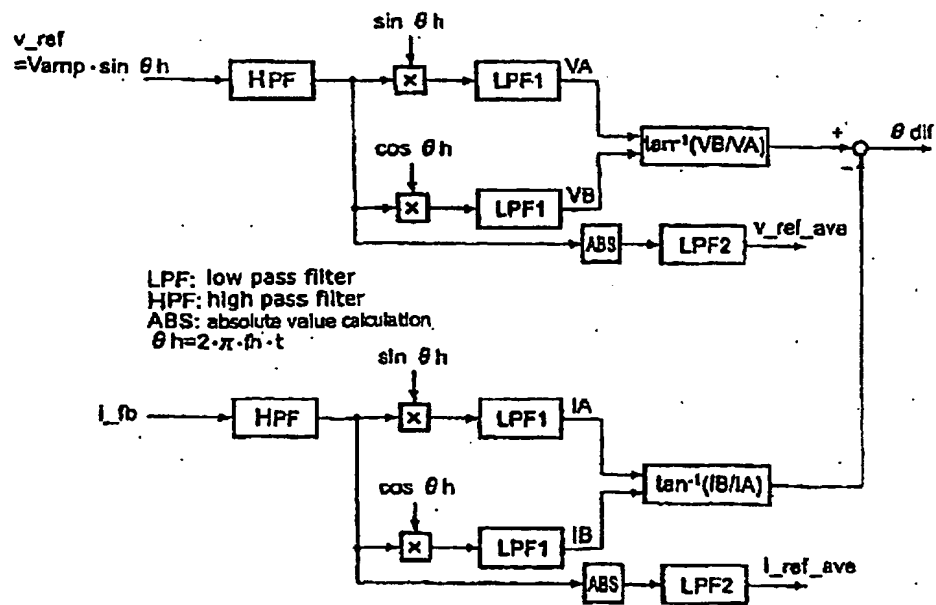


Fig. 18

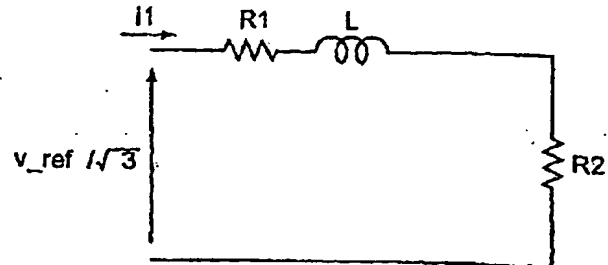


Fig. 19

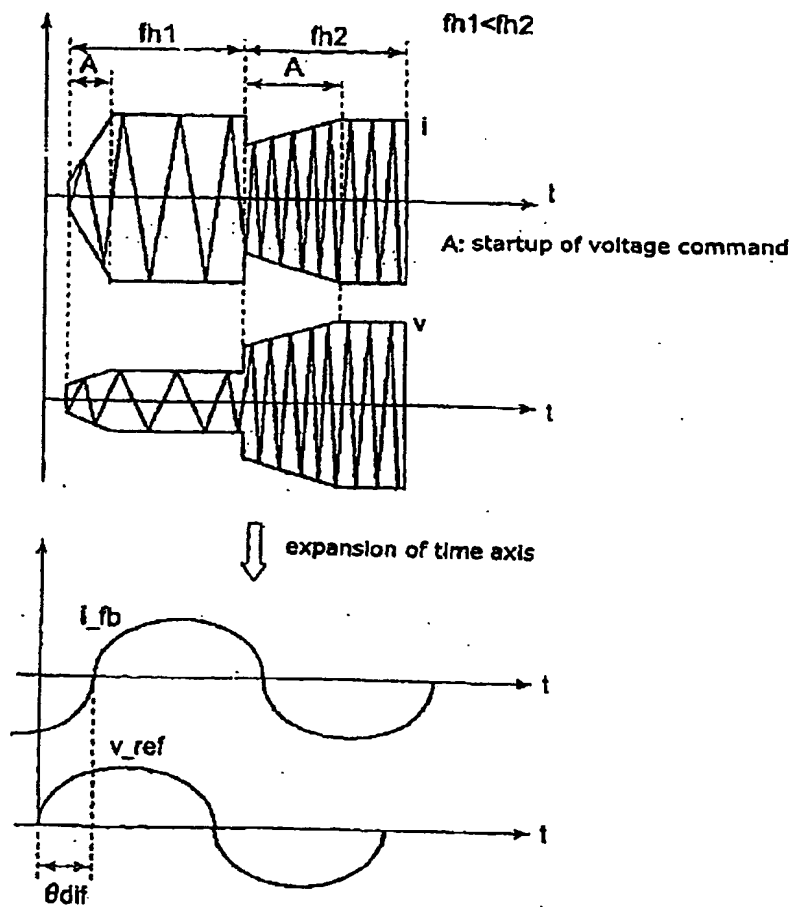


Fig. 20

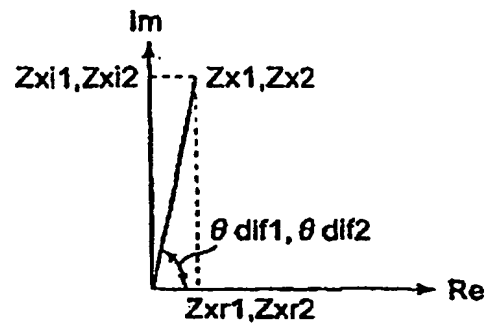


Fig. 21

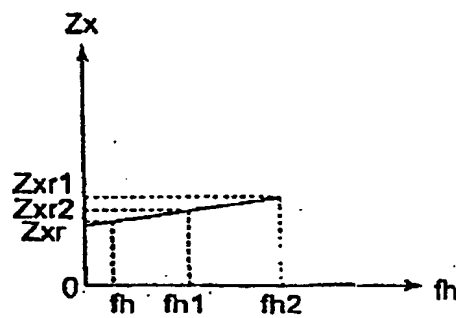
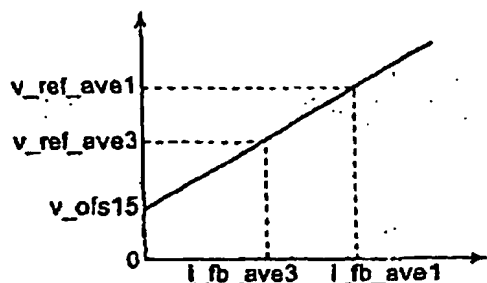


Fig. 22(a)

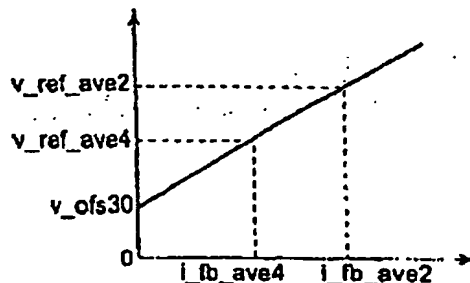


$$v_{ofs15} = (v_{ref_ave1} - v_{ref_ave3}) / (i_{ref_ave1} - i_{ref_ave3}) * (-i_{fb_ave3}) + v_{ref_ave3}$$

$$Zx1 = (v_{ref_ave1} - v_{ofs15}) / \sqrt{3} / i_{fb_ave1}$$

Zx1: Impedance at 15Hz

Fig. 22(b)



$$v_{ofs30} = (v_{ref_ave2} - v_{ref_ave4}) / (i_{ref_ave2} - i_{ref_ave4}) * (-i_{fb_ave4}) + v_{ref_ave4}$$

$$Zx2 = (v_{ref_ave2} - v_{ofs30}) / \sqrt{3} / i_{fb_ave2}$$

Zx2: Impedance at 30Hz

Fig. 23

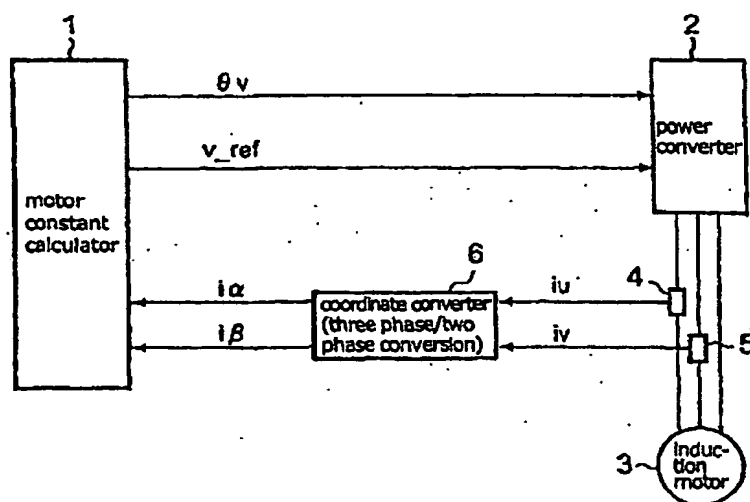


Fig. 24

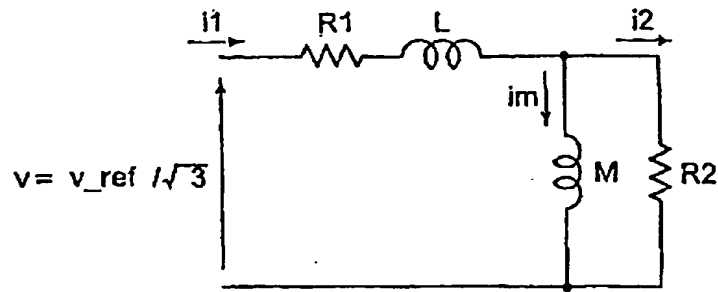
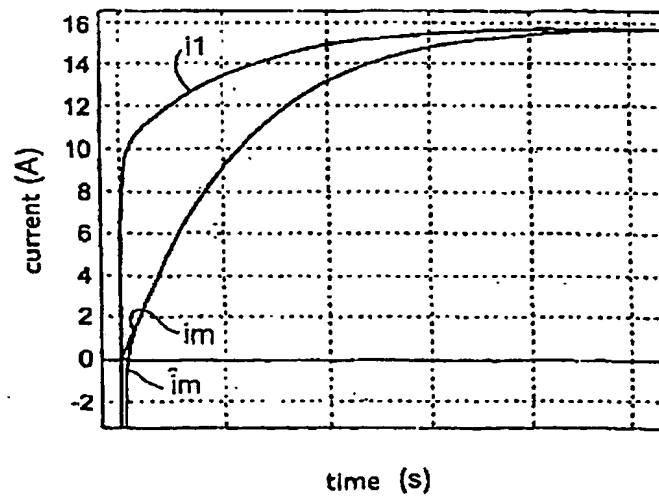


Fig. 25



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP01/05844

A. CLASSIFICATION OF SUBJECT MATTER Int.Cl. ⁷ G01R 31/34		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) Int.Cl. ⁷ G01R 31/34		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1926-1996 Jitsuyo Shinan Toroku Koho 1996-2001 Kokai Jitsuyo Shinan Koho 1971-2001 Toroku Jitsuyo Shinan Koho 1994-2001		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, A	JP 2000-312497 A (Hitachi, Ltd.), 07 November, 2000 (07.11.00), (Family: none)	1-3, 11-13
A	JP 62-42074 A (Meidensha Corporation), 24 February, 1987 (24.02.87), (Family: none)	1-6, 11-15
E, A	JP 2001-194433 A (Toyo Electric Mfg. Co., Ltd.), 19 July, 2001 (19.07.01), (Family: none)	7-10, 16-19
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "B" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed		"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "Z" document member of the same patent family
Date of the actual completion of the international search 13 September, 2001 (13.09.01)		Date of mailing of the international search report 25 September, 2001 (25.09.01)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.		Authorized officer Telephone No.

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